THE CREATION OF A COURTYARD MICROCLIMATE THERMAL MODEL FOR THE ANALYSIS OF COURTYARD HOUSES

A Dissertation

by

AMR BAGNEID

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

DOCTOR OF PHILOSOPHY

August 2006

Major Subject: Architecture

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Approved by:

Chair of Committee,	Jeffrey Haberl
Committee Members,	Malcolm Andrews
	Mark Clayton
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August 2006

Major Subject: Architecture

ABSTRACT

The Creation of a Courtyard Microclimate Thermal Model for the Analysis of Courtyard Houses. (August 2006)

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Chair of Advisory Committee: Dr. Jeffrey Haberl

This research is an effort to revive the use of courtyard housing clusters in a modern context, which were traditionally known for their distinctive passive cooling performance. The goal is to promote energy efficient design in hot-arid climates and temperate climates by reviving the use of courtyard housing clusters.

The objective is to introduce a simplified thermal model that simulates the courtyard microclimate, which has been tested with actual field data from a case study house. The case study house was an indigenous courtyard house in Cairo, Egypt that was built around 1400 AD, having an area of about 5000 sq. ft. (i.e., comparable to the size of a single-family house) with heavy thermal mass. To accomplish this, a finite difference thermal network model was created for simulating the case study courtyard microclimate. The finite difference (FD) model showed validity as it calibrated very well against field data. This model allowed running parametric sensitivity studies on the courtyard thermal simulation factors: air change rates, thermal mass, solar absorption, wall and floor emissivity, ground temperature, cloud cover, and ambient air temperature. The results of the parametric analysis showed that the model was sensitive to variations in the air change rates, solar absorptivity, and ambient air (rooftop) temperatures.

The courtyard microclimate model was then used in combination with thermal simulation software (DOE-2) to analyze the thermal performance of the case study house, which was also validated with measured field data. The DOE-2 program showed

limitations when applied to the case study, non-conditioned building, and showed a convergence deficiency when simulating high thermal mass buildings. The DOE-2 program did not perform well in simulating the impact of changes in thermal mass as compared to previous published field measurements. The proposed combinations of the FD microclimate/DOE-2 simulation did not perform as well as the FD microclimate simulation.

The FD courtyard microclimate simulation model with onsite data for calibration is advantageous in introducing for the first time the ability to perform computer simulations on any number of proposed courtyard design alternatives for reaching optimum thermal performance.

DEDICATION

To courtyards
in their ninth millennium birthdate
for all the attributes they had to offer to the occupants of buildings
I present what is considered to be the first calibrated computer program
for the simulation of its microclimates
hoping that courtyards will receive the consideration they deserve in
architectural design.

ACKNOWLEDGMENTS

"In the name of Allah, Most Gracious, Most Merciful [Qur'an, 1:1]… whoever expects to meet his Lord, let him work righteousness, and, in the worship of his Lord, admit no one as partner [Qur'an, 18:110]. God forgiveth not that partners should be set up with Him…[Qur'an, 4:48]" (Ali, 1999). Thanks and gratitude are due to Allah for whom this work would not take place except with His will and His support, wishing that it will show among my good deeds in the latter day.

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NOMENCLATURE

A	Surface Area (m^2) ($ft.^2$)
ACH	Air Change per Hour
Δt	Increment in Time
Δx	Increment in Distance
ASHRAE	American Society for Heating Refrigerating and Air-conditioning Engineers
Bi	Biot Number
CLAC	Central Laboratory for Agricultural Climatology
C_p	Specific Heat (2 kJ/kg · K) (Btu/(lb_m· °F))
δ	The Solar Declination
Fo	Fourier Number
ϕ	Latitude
FD	Finite Difference
h	Convection Heat Transfer Coefficient ($W/m^2 \cdot K$) ($Btu/h \cdot ft.^2 \cdot °F$)
I_0	Extraterrestrial Solar Radiation (W/m^2) (Btu/ (h · $ft.^2$))
I_{dif}	Diffuse Solar Radiation (W/m^2) (Btu/ (h · $ft.^2$))
I_{glo}	Global Horizontal Solar Radiation (W/m^2) (Btu/ (h · $ft.^2$))
IWEC	International Weather for Energy Calculations
K_{wall}	Thermal Conductivity (W/m · K) (Btu/h · ft. · °F)
k_T	Hourly Clearness Index
m	Mass Airflow Rate (lb/hr)
ρ	Density (kg/m^3) ($lb_m/ft.^3$)
Q	Energy (Btu/hr)

$T^{P+1}{}_{Tc}$	Future Node Temperature at Time p+1
$T^{P}{}_{Tc}$	Node Temperature at Time p
TMY	Typical Metrological Year
TRY	Test Reference Year
ω	The Hour Angle
$\bar{y}$	Average of the n Data Points
$\hat{y}$	Simulation Predicted Datum
y_i	Measured or Utility Datum
θ_S	Zenith Angle of the Sun (Degrees)

CHAPTER I

INTRODUCTION

1.1 Background

The International Energy Agency (IEA) projected that world oil production will peak as early as 2025 (Kerr, 1998), and at that time there would be significant increases in oil prices. As a result, buildings will need to be more energy efficient than they currently are, and designs should begin to rely more on renewable energy resources to meet the energy needs for buildings. One of the areas to look for energy-efficient architecture might be to go back and reinvestigate traditional architecture such as courtyard houses (Fathy, 1989). Courtyard houses are one of the traditional building types that have existed for thousands of years (Schoenauer, 1981), showing advantages over pavilion-type building forms (i.e., free-standing buildings without a courtyard) including thermal efficiency (Ahmad et al., 1985). The courtyard is the heart of the courtyard house. The courtyard shape, proportions, size, orientation, finishing materials, landscape, as well as the design of windows opening onto it, internal spaces enveloping it, and the housing cluster around it integrate to constitute the thermal performance of the courtyard house (Bagneid, 1989) (see Appendix A). The continuation of this architecture has been hampered in several of its homelands resulting in a break in its evolution because traditional courtyard-housing clusters do not complement the rapid urban changes of the modern era (i.e., technology, density, etc.) (Abdul-Wahab, 1991; Reynolds, 1995). This situation has attracted several researchers to propose modern designs for courtyard housing clusters (Akbar, 1981; Moustapha and Coste, 1987; Reynolds and Lowry, 1995; Elmas, 1992) (see Appendix A).

Pavilion-type (free-standing opening outward) houses that are less responsive to human needs (Al-Hussayen, 1995); and are more consumptive of natural environmental resources

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This dissertation follows the format of *ASHRAE Transactions*.

(Ahmad et al., 1985), replaced courtyard houses in many new neighborhoods of cities that used to be the homelands of courtyard houses. Nevertheless, residential courtyards continue to appear in new housing compounds of private institutions (Kattan-GIBB, 1983). Unfortunately, computer models capable of evaluating the thermal performance of courtyard buildings remain outside the domain of most building simulation software (Al-Mumin, 1996). This is because the current generation of thermal simulation software does not contain the necessary modules to accurately simulate the microclimate generated within a courtyard and its interaction with the surrounding house, making the software unable to simultaneously simulate the effects of both the microclimate inside the courtyard space and exterior weather conditions around the building (Al-Jared, 1991). If architects, city planners, and other decision-makers had such accurate evaluation tools for assessing the performance of courtyard houses, the courtyard house may once again become a preferred design for sustainable urban dwellings.

1.2 Purpose and Objectives

The purpose of this research is to help promote energy efficient architectural design in hot-arid and temperate climates by reviving the use of urban courtyard housing clusters in a modern context. Such houses were traditionally renowned for their distinctive energy–efficient performance. The objective is to develop an accurate thermal simulation methodology for the microclimate generated within courtyards that can be combined with building energy simulation software (i.e., DOE-2), and to demonstrate the use of the new combined model by comparing it to measured data from a case study courtyard building.

1.3 Hypothesis

This research will generate a model that accurately simulates the courtyard microclimate; this model would be validated against actual field data for an indigenous courtyard house in Cairo, Egypt. The courtyard microclimate model will be used in combination with thermal simulation software (DOE-2) in an attempt to improve the modeling of courtyard buildings to provide a more accurate assessment of their thermal performance. The predicted thermal performance will be compared against measured field data from a case study house. It is believed that the courtyard microclimate in hot-arid or temperate climates, if properly integrated with thermal mass can produce a passively-cooled structure.

1.4 Organization of the Dissertation

This chapter has discussed the background of the proposed research topic and the purpose and objectives of the research.

Chapter II surveys and discusses previous research in courtyard field monitoring, airflow wind-tunnel and CFD simulations for courtyards, thermal simulation techniques for courtyards, and urban courtyard housing projects.

Chapter III discusses the significance of the study and contributions in this research area. The scope and limitations of the research as well as the development of procedures used in this research are also discussed in this chapter.

Chapter IV discusses the methodology applied in the research. It describes the case study house, the simulation using DOE-2, and the finite difference (FD) model in detail.

Chapter V discusses the field data collection and analysis. The development of the FD computer model along with its sensitivity runs are also presented and discussed. The application of the combined FD/DOE-2 simulation for the courtyard house are also presented and discussed.

Finally, Chapter VI summarized the methodology, derived conclusions, and proposed recommendations for future research in this area.

CHAPTER II

LITERATURE REVIEW

This literature review covers four basic aspects related to residential courtyard houses: previous field studies that include field measurements about the passive cooling potential of courtyards, previous studies about airflow patterns inside courtyards, previous studies about thermal simulation programs and the prediction of the thermal performance of courtyard buildings, and urban courtyard housing projects. Also, calibration procedures for thermal simulations were reviewed.

2.1 Courtyard Field Thermal Monitoring

Most of the existing literature on courtyard buildings is mostly descriptive of the architectural features (MacIntosh, 1975). Some contains information about its measured thermal performance (Hyland, 1984). One study includes analyses on courtyard building design aspects including the presentation and analysis of the thermal monitoring of several courtyards in Mexico and Spain (Reynolds, 2002).

Few case-studies have demonstrated why the thermal comfort conditions inside courtyards in hot-arid and temperate climates are significantly cooler than the prevailing ambient weather conditions. Ahmad et al. (1985) monitored a traditional courtyard house within a six centuries old indigenous urban cluster and compared it to a modern detached house within a new urban development under summer and winter climates of Ghadames, Libya. In the summer, the ambient temperature ranged between 20 C (68 F) and 40 C (104 F). During this time the temperature inside a traditional courtyard house remained almost constant at 28 C (82.4 F), while inside a modern detached house it ranged between 34 C (93.2 F) and 39 C (102.2 F). In the winter, the ambient temperature ranged between 4 C (39.2 F) and 23 C (73.4 F), while the temperature inside the traditional courtyard house remained nearly constant at 12 C (53.6 F). In the modern house, during the winter, it ranged between 12 C (53.6 F) and 14 C (57.2 F). The authors made a comparison between the two houses regarding the roof/floor area, exposed/floor area, window/floor area, perimeter to floor area, and the overall heat transfer coefficient, all of which showed much lower values for the traditional house. Of most importance to this study is the fact that the mass/floor area ratio of the courtyard house was double that of the modern house which was already large (1620 kg/m2 or 332 lb/ft.2), compared to lightweight wooden houses (50-75 lb/ft.2). This study also showed the thermal comfort superiority of an indigenous courtyard house over a modern pavilion-type house.

Bagneid (1989) conducted single-variable, comparative experiments on two identical detached courtyard buildings varying the courtyard (i.e., the size is approximately 30 ft. wide x 60 ft. long x 20 ft. in height) floor treatment during the summer (June) climate of Phoenix, Arizona. The results showed that in the hottest hours of 3 clear days, the temperature underneath the arcade of the courtyard having a water pool covering its entire floor with two water sprays was lower than the ambient temperature by about 5 C (9 F), while inside the courtyard having a dry concrete floor it was lower by only 2.5 C (4.5 F). During a one week period, the courtyard with the evaporative spray had a slightly cool to cool Predicted Mean Vote (PMV) (i.e., the thermal comfort index by Fanger (1981)) 15% of the time. These PMV coolness levels had no occurrence in the courtyard with a dry concrete floor, which had an above warm PMV occurring 50% of the time compared to 25% in the courtyard having a pool with fountains. The results show the courtyard as being an effective microclimate generator.

Reynolds and Carrasco (1996) monitored a traditional courtyard house that was remodeled on a medieval Andalusian structure in Bornos, Spain, which was exposed to a hot dry summer climate. They concluded that a retractable shading over the courtyard, watering the patio’s absorbent floor (i.e., evaporative cooling), opening the windows for night ventilation, and high thermal mass contributed significantly to the passive thermal cooling of the house. While the outdoor temperature ranged between 22 C (71.6 F) to 44 C (111.2 F) for three days in August the indoor temperature at a ground floor room opening onto the courtyard maintained temperatures in the range of 26 C (78.8 F) and 29.5 C (85.1 F). The first floor rooms maintained temperatures of 27.5 C (81.5 F) to 33

C (91.4 F). The Reynolds and Carrasco study clearly demonstrated the thermal benefits of skillful manipulation or ‘thermal sailing’ of passive cooling strategies in accordance to daily climatic cycles (i.e., retractable shading, evaporative cooling, and night ventilation), which results in improved indoor thermal comfort.

2.2 Airflow Wind-tunnel Experiments and CFD Simulations

In hot-arid and temperate climates it is necessary to carefully control the flow of ambient air inside courtyards in order to preserve its microclimate.

The Murakami el al. (1977) article was the earliest quantitative study on courtyard ACH found in the current literature review. The paper studied the influence of the outside wind on the airflows inside half-enclosed spaces (including courtyards) by conducting field experiments and wind-tunnel tests. Field experiments were compared to wind-tunnel tests on a cubic courtyard and a similarity law that related the two was proposed. Field experiments showed 240 and 480 ACH at wind speeds of 3 m/s and 6 m/s respectively. However, the author states in his conclusion that the rate of air change in large scale courtyards is between 5 and 100. The results of the courtyard ACH from this article along with the results from Walker et al. (1993) are presented in Table 2.1 to be considered while selecting an appropriate ACH for the case study courtyard.

A study by Al-Jared (1991) presented design guidelines for a limited number of residential courtyard forms with respect to the flow of ambient forced wind. The following are the significant research findings that relate to the proposed study:

a) Correlations based on wind speed and ambient temperatures were developed to estimate the convection heat transfer rate from the surfaces of courtyards. He suggested the use of these correlations in energy analysis software to estimate convection heat transfer rates from the surfaces of courtyards of geometries and conditions similar to the investigated cases. However, a review of the literature published after Al-Jared showed no subsequent research using this approach in simulating the courtyard microclimate

From these convection coefficients the following were applied in the Finite Difference courtyard model since they were originally related to a two story house similar to the case study house:

For windward wall $h = 0.371 + 1.51V$ $W/m^2.c$

For leeward wall $h = 0.235 + 1.02V$ $W/m^2.c$

V is the wind speed outside the courtyard. Considering an average wind speed above the case study courtyard of 2 m/s, then:

For windward wall $h = 0.371+1.51*2 = 3.391$ $W/m^2.c = 0.59$ $Btu/hr.ft.^2.F$

For leeward wall $h = 0.235+1.02*2 = 2.275$ $W/m^2.c = 0.40$ $Btu/hr.ft.^2.F$

Table 2.2 tabulates the values for the combined convection/radiation coefficients for application in the finite difference (FD) courtyard thermal network model.

b) The vortex created in the courtyards (aspects ratios =0.5, 0.75, 1.5, & 2) showed a roughly circular pattern that elongates to accommodate to the courtyards' height-to-width ratio. These results were contradicted later with the research findings of Shao et al. (1993).

c) Vector plots were produced showing the effects of the introduction of architectural elements such as overhangs, pergolas, and parapets as well as varying wind directions on the changes to the airflow patterns inside the courtyard, which are significant elements in the design of courtyards. These plots also show the sensitivity of the airflow patterns inside courtyards to the form of the courtyard.

Shao et al. (1993), and Walker et al. (1993), in two related papers, examined the adequacy of natural ventilation rates in courtyards including contaminant dispersal, and the effectiveness of ventilation in rooms opening onto a courtyard in order to evaluate existing design regulations for residential buildings having courtyards in England. Their computational fluid dynamics (CFD) studies investigated the mechanism of ventilation of courtyards including a parametric study of the key features of flow, building and surroundings that impact courtyard ventilation. Their model used an existing eight-story building with light-wells (i.e., courtyards). The following are some significant research findings that relate to the case study:

Table 2.1 Courtyard Measured ACH Rates

Reference	Space Courtyard	Wind speed	ACH Field	ACH CFD predictions	Notes
Walker et al. (1993)	Courtyard (light well) 16m x 7m x 27 m deep (eight story building)	2-3 m/s (above roof) 3.3 m/s	50 45	43 (2m/s wind speed) 35	- Recommended: 10 ACH (conservative estimate) - Field Smoke tests showed adequate flow of fresh air deep into the courtyard.
Murakami el al. (1974)	The courtyard have equal width, height and length = 2.4 m. and the roof depth was 1.2 m.	3 m/s 6 m/s	240 480		Note: The author states in his conclusion that the ACH in large scale courtyards is between 5 and 100.

Table 2.2 Convection Coefficients Applied to the FD Model

	Exterior walls			*Courtyard walls*	
	ASHRAE surface Convection coefficients (Btu/hr.ft.^{2} .^{o}F)	ASHRAE surface Radiation coefficients (Btu/hr.ft.^{2} .^{o}F)	ASHRAE (1998) combined Convection/Radiation Coefficients (Btu/hr.ft.^{2} .^{o}F)	Al-Jared (1991) Courtyard walls Convection coefficients (Btu/hr.ft.^{2} .^{o}F)	Combined convection/radiation convection coefficients (Btu/hr.ft.^{2} .^{o}F)
Vertical walls Convection coefficients	0.54	0.93	1.47	Windward wall 0.60 Leeward wall 0.40	Windward wall 0.60+0.93=1.53 Leeward wall 0.40+0.93=1.33
Exterior Upper surface of floor/ceiling	0.17	0.92	1.09		Courtyard floor: 1.09

a) The mechanism of ventilation, investigated via the CFD studies, showed that there were two distinct airflow patterns. The first comprises a circulation at the top of the court, a ‘top vortex’, with stagnant air below. The second is a vortex that occupies the full width and depth of the courtyard, a ‘full vortex’. The full vortex, which gives an efficient air exchange, was shown to be created when the separated flow at the top upwind edge of the building re-attaches at or near the courtyard opening at roof level. CFD simulation showed that surrounding buildings of similar height assist formation of the full vortex. These finding disagree with the previous wind-tunnel work by Al-Jared (1991), who reported an elongated vortex due to the fact that the courtyard was surrounded by an extended roof being attached to one of the wind-tunnel sides, and a top vortex would not provide an efficient air exchange throughout the court.

b) Parametric studies (i.e., increasing the building's width or height, increasing the distance of the courtyard from the upwind face, having wind not blowing normal to the façade, having surrounding buildings of similar height, etc.) produced results that constituted a coherent model that the authors considered as a basis for design guidance that can only be interpreted qualitatively since many of the indeterminate factors that influence courtyard airflow in the real world were not measured. This study emphasized the importance of simulation tools such as wind-tunnels or CFD programs in the evaluation of courtyard airflow evaluation. A comparison was made between full-scale measurements, CFD, and wind-tunnel tests of a scale model (1/200) for the above predictions of a case study eight-story office building with two light-wells. Within broad limits of accuracy, full-scale measurements compared quite well with the CFD predictions in terms of air change per hour (ACH – One ACH means a volume of outdoor air equal to the volume of the space being ventilated has entered that space in one hour) and the airflow pattern was found to be consistent. Field Smoke tests showed adequate flow of fresh air deep into a 16m x 7m x 27 m deep courtyard. When the wind speed above the roof was 2-3m/s, a 50 ACH was recorded. The CFD simulation showed 43 ACH while the wind speed above the roof was 2m/s. These ACH values were listed with other studies in Table 2.1 to be used to guide the courtyard ACH estimations for the proposed finite difference (FD) model.

c) However, the CFD predictions only agreed with the scale model when the wind was parallel to the long side of the courtyard and did not agree when the wind was parallel to the short side of the full-scale courtyard, which may be due to the fact that the CFD model included sheltering. Agreement in the results only occurred when the CFD simulation of the building was performed at the scale of the model, rather than at full-scale. This directs attention to the importance of full-scale measurements.

Al-Bakri (1997) measured on-site ventilation rates and temperatures for a set of traditional mud brick courtyard houses in the central desert of the Arabian Peninsula. The Two houses studied included both measurement types, where one was a one story building and the other two story building similar to the case study house of the current study. Considering the latter, two ground floor bedrooms were monitored. Openings existed on more than one wall in both rooms. The openings area were 0.44 m^2 and 0.48 m^2 and the space volumes were 175 m^3 and 125 m^3 respectively making ratios of openings area/ room volume of 0.002 & 0.004 respectively. The ACH for the two bedrooms were 0.72 and 0.97 respectively while the outdoor wind speed was 0.7 m/s.

In the study by Al-Bakri the time lag showed to be 2.5 hours (4 hrs for the second house) and included diurnal outdoor, indoor, & wall surface temperature ranges of ~13.5, 3, and 1.3 ^{o}C respectively (~15.5, 5, and 2^{o}C for the second house).

Wind-tunnel tests measured the pressure coefficients on the openings where the CFD simulation showed to be between 1 to 30% of measured ACH rates, and that thermal mass reduces air temperature by 1.5^{o}C. The HTB2 Thermal simulation software (Lewis and Alexander, 1990) was applied and showed to be within 2^{o}C and 1^{o}C for air and surface temperatures respectively. There was about 1 hour thermal lag between the predicted and the measured thermal lag air temperature.

Computer simulations using HTB2 software showed that increasing the ventilation rates inside a room onto the courtyard from 1 to 3.5 made the house warmer during the day by 0.5 – 2^{o}C and cooler during the night by 1- 4^{o}C.

The study compared traditional courtyard houses with a modern pavilion-type house where the courtyard house performed better than the pavilion-type house even after adding insulation, shading and double glazing.

The author concluded that the combination of thermal mass and low ventilation rates provide a thermally comfortable indoor space. Field measurements for ventilation rates and time lag are very rare in the literature; those provided by Al-Bakri (1997) will be used for comparison purposes with the current case study simulations. The ACH rates findings of this research are summarized in Table 2.3.

Table 2.3 Rooms Opening on a Courtyard Measured ACH Rates

<table>
<tr><th rowspan="2">Reference</th><th rowspan="2">Rooms</th><th rowspan="2">Wind speed</th><th colspan="2">ACH</th><th rowspan="2">Time lag</th><th rowspan="2">Notes</th></tr>
<tr><th>Field</th><th>CFD predictions</th></tr>
<tr><td rowspan="2">Al-Bakri (1997)</td><td>House 1 (two levels):
Openings area/ space volumes= 0.48 m2/ 125 m3= 0.004
Floor height = 5m</td><td>outdoor
0.7 m/s</td><td>0.97</td><td>0.46
1 to 30% of measured rates</td><td>4 hrs (diurnal indoor & wall temp: 15.5 - 2)</td><td rowspan="2">- Traditional mud-brick two story courtyard houses.
- Records were taken from two bedrooms at the ground floor.
- Openings were on ambient air.
- The doors ‘on courtyards’ were fully open all the time</td></tr>
<tr><td>House 2 (one level):
Openings area/ space volumes= 0.44 m2/ 175 m3= 0.002
Floor height = 5m.</td><td>0.7 m/s</td><td>0.72</td><td></td><td>2.5 hrs (diurnal indoor & wall temp.: 13.5 – 1.3)</td></tr>
</table>

Hall et al. (1999) conducted wind-tunnel experiments on the dispersion of contaminants discharged from the bottom of courtyards that covered square-plan, solid courtyard blocks with aspect ratios of depth/width varying from 5 down to 0.1. Parameters investigated were the depth of the building surrounding the courtyard, the presence of an opening through the building, wind direction, the presence of surface clutter (resembling trees) inside the courtyard, and stratification of air in the courtyard. The following are some significant research findings that relate to the case study proposed for this work:

a) The depth of the building around the courtyard was tested against airflow patterns covering the basic value of depth-to-width (D/W) = 1 up to a value of D/W = 5. With an aspect ratio of unity, increasing the building depth increased the concentration of contaminants at the bottom of the courtyard steadily in a linear pattern (i.e., an increase of 500% from the unity aspect ratio). This result is very informative, because it shows significant microclimate performance variation in contaminant concentration between a modern detached and a traditional compact courtyard building.

b) Opening an entrance on the side of the courtyard was found to have an impact that varies with the wind direction in relation to the position of the entrance. Comparing a courtyard of aspect ratio equal to 1.0 with a tunnel entrance at the center of one of the courtyard's sides (similar to the case study house) to a closed courtyard, the concentrations were generally less than or equal to one-half that of the closed courtyard except in the 90^{o} and 180^{o} wind directions, when they were greater. This study points towards the importance of courtyard openings and their orientation to prevailing wind flows. In relation to the monitoring of the case study courtyard house in this study, no airflow currents were observed during the monitoring period at the floor level of the main courtyard or at the entry gateway while the average wind speed was ~7 mph (3.3 m/s) (at the airport, about 10 miles away from the case study house), which downplays the role of forced convection even though the house have an open entrance gateway

In general, the experiments in the previous literature showed that courtyards have conditions that are advantageous to microclimate generation and preservation. The effects of the parameters investigated on contaminant concentrations were complex and variable, which indicates that simple guidelines may not be sufficient for designing courtyards of varying shapes with varying openings into the courtyards.

The results of wind-tunnel tests in the previous studies provide a basis for informative design tools for predicting the degree of mixing between the ambient air and the microclimate generated within courtyards. The test variables in the previous papers covered the courtyard proportions, wind orientation, neighboring buildings, trees inside the courtyards, etc.

2.3 Thermal Simulation Techniques and Courtyards

Previous studies have indicated that the current generation of thermal simulation software is unable to directly simulate the effects of both the interior weather conditions within the courtyard space and the exterior weather conditions without extensive modification (Al-Jared, 1991; Al-Mumin, 1996). In general, this is because the software considers that the courtyard weather file is the same as the ambient weather file. The following is brief review of the work conducted in this direction:

a) Al-Mumin (1996) developed a computer program that predicts the thermal performance of an underground courtyard houses using a general purpose program used to solve the partial differential equations for heat conduction with a finite difference method in two dimensions. This appears to be the first courtyard house thermal model found in the literature, although it does not relate directly to the current research since it dealt with earth-sheltered courtyard houses.

b) Chen et al. (1997) presented formulas for the heat transfer balance in courtyards considering conduction, convection, radiation and evaporation. Unfortunately their thermal formulas were considered only simplified assumptions and were presented in a generic context (i.e., courtyard height= 100m (~330 ft.)).

c) Alvarez et al., (1998) presented a thermal model for a courtyard that considered relating the temperature distribution with the airflow pattern, characterized with the air changes per hour (ACH) at intermediate and top zones of the courtyard. The model was not validated. Results showed the need for a model that considers more variables, such as the one that will be proposed in the current research.

d) Coronel and Alvarez (2001) monitored narrow streets and courtyards of a traditional Andalusian neighborhood in Seville, Spain. They conducted computational thermal simulations combined with a CFD analysis to simulate airflow (i.e., Fluent software) for the monitored narrow streets (alleys and not courtyards).

e) In general, the limitations of the most commonly used current thermal simulation software (i.e., DOE-2, BLAST) are:

   1. Inter-zonal airflow are not usually simulated
   2. Heat transfer is one dimensional.
   3. One ambient weather file.
   4. No wetted surfaces (i.e., moisture transfer not usually considered).
   5. Combining CFD with thermal simulation software is still in the research stage.

However, Energy Plus software recently has been linked to CFD software.

f) A correspondence was made with the User Support office (see Appendix (E)) for EnergyPlus (2003) software which is the new Department of Energy-supported project that merges two major building energy simulation programs, DOE-2 and the Building Loads Analysis and System Thermodynamics (BLAST). The question was whether the program can simulate the microclimate inside a courtyard or not, their attached reply proposes an approximated simulation.

No previous studies could be found that describe procedures for the modeling of a courtyard microclimate that combined CFD with a thermal analysis program (i.e., DOE-2, BLAST, or EnergyPlus). A courtyard, being a semi-enclosed space exposed to ambient weather, has its own special characteristics regarding natural ventilation airflow within it. Therefore, thermal simulation programs such as DOE-2 cannot simulate a courtyard with natural ventilation, unless the user can resolve the following:

1. Estimating hourly airflow rates into/ out of the courtyard.
2. Estimating hourly heat transfer coefficients, which are based on estimated airflow rates.

In conclusion, the literature review of courtyard simulations shows the need for a simulation that would predict the thermal performance of courtyard houses that considers the microclimate of the courtyard.

2.4 Calibrated Simulations

Calibrated simulations are thermal simulations that are adjusted so that their simulated outputs match monitored data from the actual building being simulated. The purpose of calibrated simulations, within the scope of this research, is to produce a calibrated input file to be used for introducing design variations to the case study building (i.e., thermal mass, attached neighboring buildings, etc.) so as to predict their thermal impact on the building's overall thermal performance. The calibrated simulation will be applied in this research to two models: the courtyard microclimate finite difference model and the DOE-2 courtyard house input model(s).

The DOE-2 energy simulation program was primarily designed to help designers predict the hourly energy use of buildings with heating, ventilating, or air-conditioning (HVAC) systems. Since the case study building has no HVAC systems, the calibrated simulation relies solely on measured temperatures. In general, the previous literature has reported on calibrated simulations to buildings that had HVAC systems and used a combination of energy and temperature-based calibrations. Therefore, this literature review will focus on the calibration methodologies and calculations appropriate for application with the non-conditioned case study house. Sources of errors in simulations include: accuracy of the simulation software, errors of input data including weather data, building thermal properties and physical assumptions or simplifications, and schedules.

2.4.1 Calibration Procedure Types

A number of studies have reported the use of calibrated simulations, Yoon et al. (2003), Haberl and Bou-Saada (1998), Soebarto (1997), Manke et al. (1995), Troncoso (1997), Sreshthaputra (2003). Three main types of calibrations were classified:

a) Calibrations based on manual, iterative and pragmatic intervention. This is the most common calibration approach to-date. It includes building data, use of onsite weather data, as-built drawings, hourly monitored data for selected days, site visits and interviews (Yoon et al., 2003).

b) Calibrations based on a suite of informative graphical comparative display.: Along with manual, iterative and pragmatic approach to calibration described in the previous section, visual graphics have been successfully applied to highlight differences and aid in the deciding of which parameters to adjust in the next iteration. Common plots include: carpet plots, 3-D time series plots, superimposed and juxtaposed binned box, whisker and mean plots, in addition to standard 2-D plots such as scatter plots and time series plots (Haberl and Bou-Saada, 1998).

c) Calibrations based on special tests and analytical procedures. These calibrations use controlled tests on lighting and HVAC systems for a few days (Blink-tests or on/off tests are used for snap-shots of end-use measurements of lighting, and motor control center electricity use (Soebarto, 1997), Short-Term Energy Monitoring (STEM) tests, which involve intrusive and controlled heating and cooling tests (Manke et al., 1996), and include a systematic approach of reconciling differences between measured and simulated data. This approach involves identifying four or five primary building parameters and another set of secondary parameters, where each of the parameters is varied one at a time from 10% to 200% of their nominal values having increments of 10% while holding the other parameters constant and computing calibration statistical indices for each sensitivity run. During the entire building calibration, the nominal value for some parameters may change more than once. However, since the input file is adjusted by modifying its parameters on trial-and-error basis until the simulation output matched the measured data, this can reduce the credibility of the entire simulation (Troncoso, 1997). It can lead the analyst to produce a physically meaningless simulation. The problem of calibration may be further compounded by the fact that it is a dynamic matching over one year not static at one condition or time frame.

2.4.2 Statistical Indices and Calibration Accuracy

While graphical methods are useful to assist in refining a simulation, the ultimate determination of acceptable calibration must use a statistical method. ASHRAE Guideline 14-2002 (ASHRAE, 2002) suggests for calibrated simulations the following two dimensionless indices to represent how well a mathematical model describes the variability in measured data:

- Normalized Mean Bias Error (NMBE): is a dimensionless estimate of the bias of the prediction, which quantifies the percentage error of difference between the measured and simulated values summed over a period.
- The Root Mean Square Error (RMSE): is the square root of the average of the sum of the squared differences between the measured and simulated values, along with the coefficient of variation (CV) which is a dimensionless measure of the RMSE.

In general, the smaller these values are the better the prediction has performed. ASHRAE Guideline 14-2002 (ASHRAE, 2002) sets an uncertainty or tolerance limit for calibrated simulation as follows: "… models are declared calibrated if they produce NMBEs within $\pm$ 10%, and CV-(RMSE)s within $\pm$ 30% when using hourly data, or 5% - 15% with monthly data". These tolerance values are based on the practical experience of the energy modelers who perform calibrated simulations.

2.5 Urban Courtyard Housing Projects

Transient heat conduction to the ground and through heavy weight walls is a major element in shaping the thermal performance of courtyard houses (Reynolds, 1995). Unfortunately, many of the previous studies have not fully addressed the issue of thermal mass in the performance of a courtyard house. Three design proposals by Akbar (1981), Moustapha (1987), and Reynolds and Lowry (1995), (See Appendix A) showed designs that did not address the thermal mass factor either in the drawings or in the accompanying text. In contrast, indigenous courtyard houses have demonstrated distinctive thermal performance while incorporating large amounts of thermal mass. Elmas (1992), developed designs for courtyard house clusters for hot-dry and for hot-humid climates in Turkey (See Appendix A). Although thermal mass was one of the factors that distinguished between the proposals for both climates, no quantitative analyses accompanied the study to support the applied thermal mass strategy.

It is worth noting that Reynolds (1995), being one of the previously mentioned design teams that did not address the thermal mass factor either in the drawings or in the accompanying text, did acknowledge the role thermal mass plays in passive cooling in courtyard houses in a paper published in the same year with his design (Reynolds and Lowry, 1995).

2.6 Summary of the Literature Review

In the literature review, thermal research on courtyards may be classified under three categories: field monitoring, laboratory tests, and thermal simulations. In addition, several modern courtyard housing projects were reviewed for potential application to the proposed research.

a) Previous reports that presented results from field monitoring studies included an investigation of the impact of floor treatment (Bagneid, 1987), as well as the combined effect of thermal mass, evaporation, and shading in a traditional courtyard house (Reynolds et al., 1996). Although the previous monitoring experiments were limited in number and type of variables investigated, their results had the advantage over computer simulations since real world conditions were used to analyze the case studies.

b) Previous wind-tunnel tests reported airflow patterns inside the courtyard for a wide range of courtyard forms and orientations, the impact of free-standing versus compact courtyard housing clusters, and the impact of having trees inside the courtyard. The effects of introducing architectural elements such as overhangs, pergolas, and parapets in the courtyard were also studied.

   In the study by Shao et al. (1993) the test results were limited to the experimental settings that were studied, since in real courtyards airflow would be sensitive to changes in a larger number of variables. In this study, wind-tunnel experiments showed that courtyards were poorly ventilating spaces that presented and maintained an interior microclimate. In addition, the courtyard microclimate is further protected from mixing with ambient wind when a shade was extended over its top, which is a practice when solar shading becomes a necessity under extreme hot climates. The literature review found that there are very few computational fluid dynamics (CFD) simulations for courtyards (Shao et al., 1993, and Walker et al., 1993), although there were some significant wind-tunnel airflow studies (Al-Jared, 1991, and Hall et al., 1999).

c) The literature review found one thermal simulation of a courtyard (Alvarez et al., 1998) that was very elementary in that it was not validated, and handled only a single thermal variable: air temperature distribution with the airflow pattern, characterized by the air changes per hour (ACH) at an intermediate and top zones of the courtyard.

d) Previously reported calibrations were based on a manual, iterative and pragmatic approach which compared simulated results with on-site data to adjust the simulation input file, while another approach accomplished calibration with systematic variations to building parameters (Manke et al., 1996) which applied non-realistic variations (i.e., 800% increase in thermal mass) of material and geometric properties. For the case study house realistic calibrations against on-site data will be considered first before any application of non-realistic variations.

e) Finally, previously reported modern courtyard housing projects in hot-arid and temperate climates mostly ignored thermal mass (see Figure 2.1). The literature review failed to turn up courtyard design tools that are based on quantitative analyses, although several qualitative design guidelines have been previously reported.

Therefore, there is a need to develop and demonstrate an accurate courtyard simulation that properly accounts for the courtyard microclimate, thermal mass, and airflow to/from the courtyard and its surroundings.

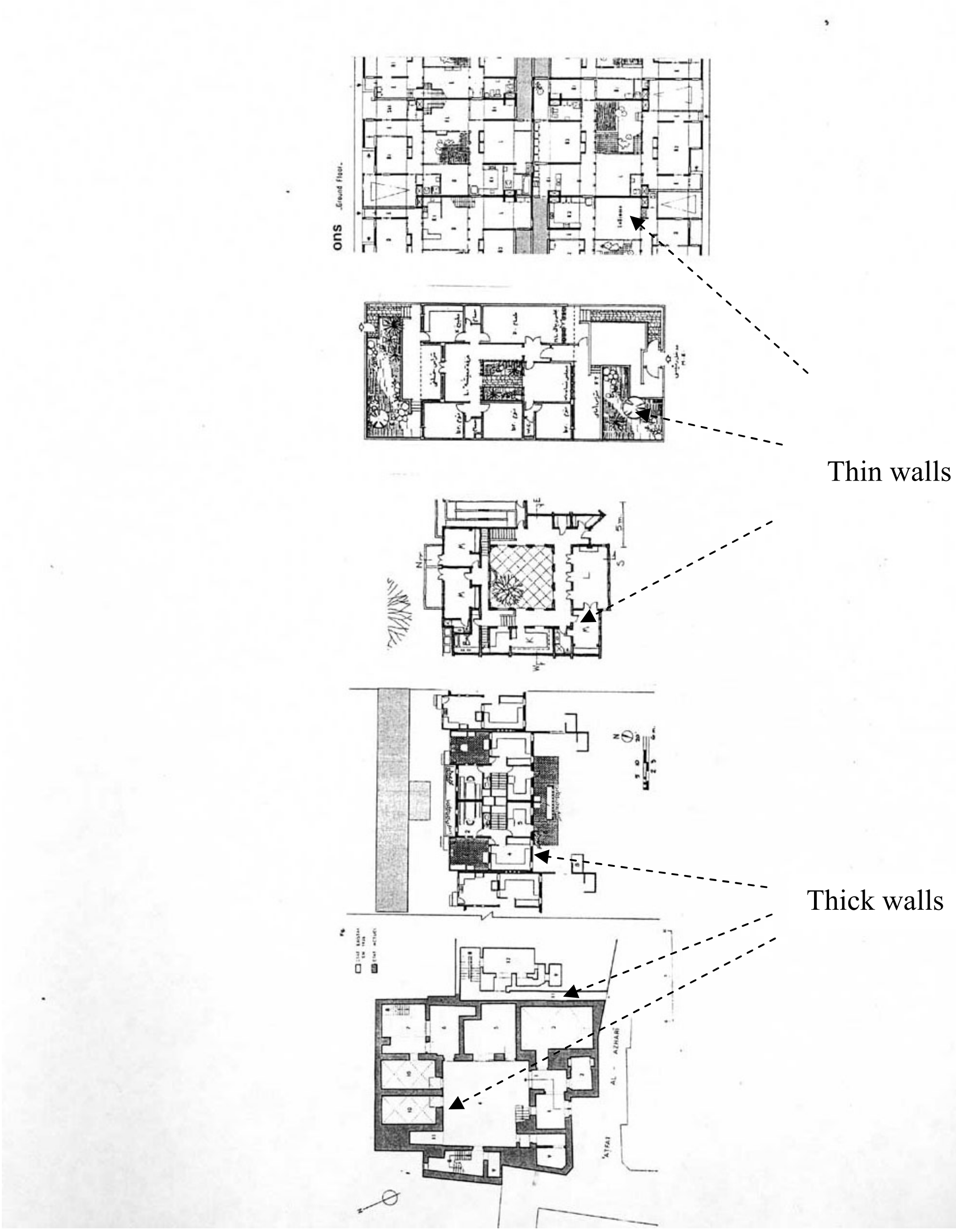


Figure 2.1 A Graphic Comparison Layout of the Ground Floor Plans of Proposed Modern Projects for Urban Courtyard Housing Clusters Models along with the Case Study Courtyard House (bottom) Showing the Mass/Void Proportion Across Them. (Note: Most of the ceiling of the ground floor case study house is made of limestone vaults - Appendix A includes detailed drawings for these courtyard housing projects.)

CHAPTER III

SIGNIFICANCE OF THE STUDY

3.1 Expected Contributions of this Research

This research will monitor and analyze the thermal performance of a case study indigenous courtyard house in Cairo, Egypt that was built around 1400 A.D. The house shares many thermal features that are common among the remaining 25 indigenous Cairene courtyard houses (Revault and Maury, 1979). During the 1400s, natural methods were the only means of achieving thermal comfort. An improved understanding on how they operate could point to effective methods that can be applied to modern courtyard houses.

This research seeks to introduce improvements to the current generation of building simulation software that will improve the modeling of the courtyard buildings to provide a more accurate assessment of their passive thermal performance. The improved model will incorporate a calibrated model of the courtyard microclimate. In the previous literature no studies could be found that proposed the use of a simulated microclimate weather file. Therefore, the current research breaks new grounds in this area. The modeling of the courtyard microclimate will facilitate the use of parametric sensitivity studies for understanding the sensitivity of courtyard design variables.

3.2 Limitations of the Research

This research will develop a simplified model of the courtyard microclimate that is calibrated to measurements from a case study building in Cairo, Egypt. This calibrated courtyard model will then be applied to a specially-designed DOE-2 simulation of the case study courtyard building to evaluate the improvements to the simulation as compared to DOE-2 simulation of the case study building without the courtyard microclimate. Therefore, although the detailed results from this study will be applicable only to the case study building, the general trends from this study and the analysis procedures will be applicable to other courtyard buildings. The courtyard microclimate model does not include a surface radiation network model. This study is limited to the thermal simulation capabilities of the DOE-2.1e version 119 program.

CHAPTER IV
METHODOLOGY

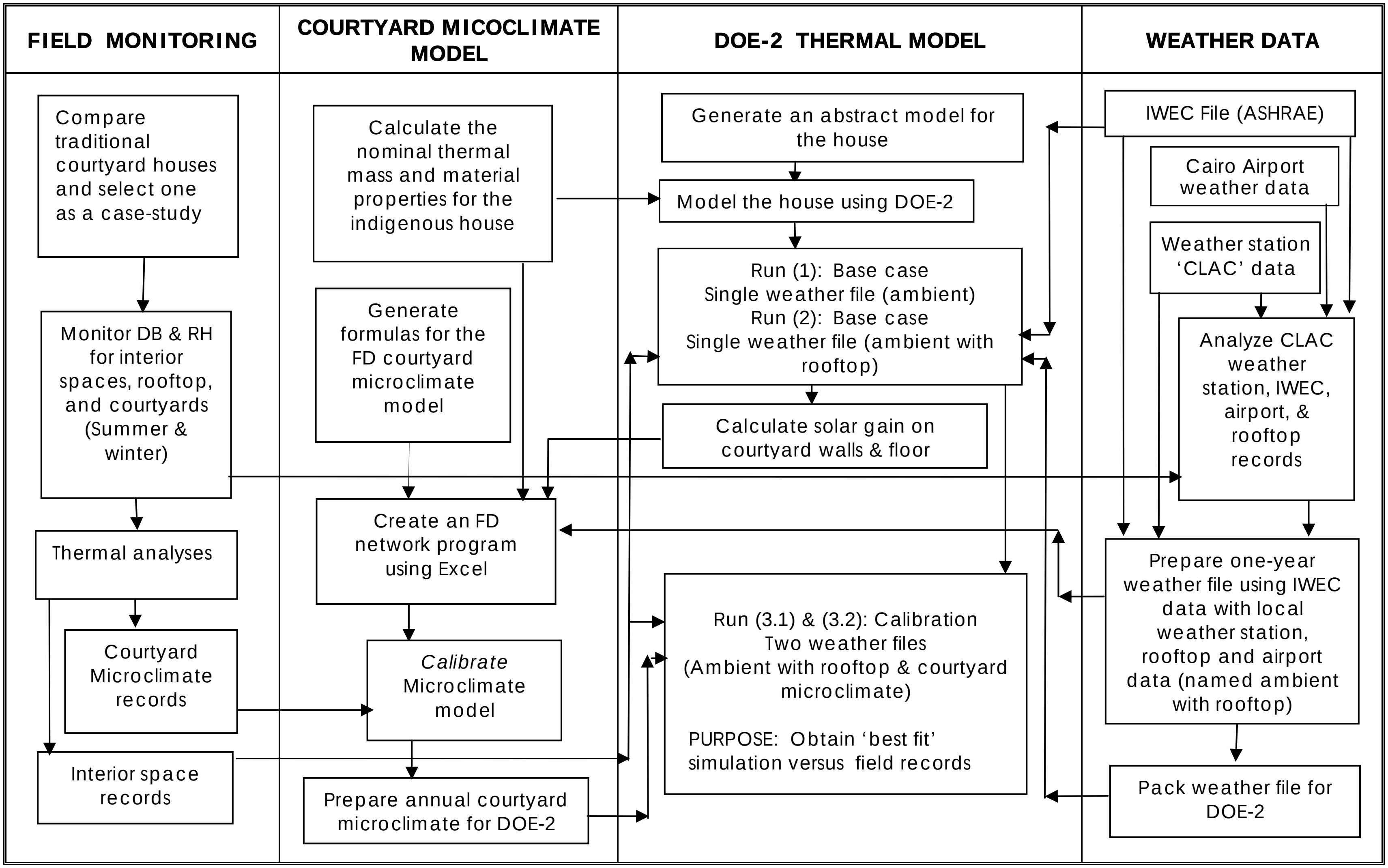
This chapter discusses the methodology used in this research. It contains descriptions of methods used to survey the case study building, measurements and data collection methods, to create a courtyard microclimate FD thermal network simulation model, and the calibrated DOE-2 simulation methods.

The research steps were:

1. Select an indigenous case study courtyard house having good passive thermal performance features to record on-site climatic conditions (i.e., dry-bulb temperature, humidity & surface temperatures).
2. Develop a representative weather file for the microclimate within the courtyard, using a finite difference (FD) model that is calibrated to the measured data from the case study courtyard house.
3. Model the courtyard house using the DOE-2 thermal simulation software. Use the new courtyard microclimate weather file along with the DOE-2 program for simulating the thermal performance of the case study house. This will be performed using specially prepared DOE-2 simulations: one with the microclimate weather file of the courtyard for those portions of the building exposed to the courtyard, and one with the ambient weather file for those portions of the building exposed to normal ambient conditions.

Table 4.1 lays out the research tasks showing the sequence of work. Research tasks are classified under 4 columns: field monitoring, courtyard microclimate model, DOE-2 thermal model, and weather data. The field monitoring column began with the selection of the case study among available houses. This was followed by field monitoring of the case study house during the summer and winter seasons followed by an analysis of the collected data. These monitored records were used in the courtyard FD model and the DOE-2 simulation. The courtyard microclimate model column began with the

Table 4.1 Layout of the Research Tasks



inventory of the case study house material thermal properties. This is followed by the generation of formulas for the FD courtyard microclimate model, which were then modeled being an explicit solution in an Excel spreadsheet program. The FD model was then calibrated against field temperature records to be used in generating an annual microclimate weather file for the DOE-2 simulation. The DOE-2 thermal model column began with the generation of an abstract model for the case study courtyard house that combines the three courtyards into one courtyard. The DOE-2 runs includes a base case using the ambient weather file, a calibrated simulation of two runs for the outer ring of the house with the ambient weather file and the second for the inner ring of the house with the microclimate weather file. The weather data column begins with the collection of data from the Central Laboratory for Agricultural Climatology CLAC weather station, Cairo airport weather station, an ASHRAE International Weather for Energy Calculations (IWEC) weather file, and the case study rooftop records. An annual ambient weather file was prepared based on IWEC data augmented with the case study rooftop temperature and humidity records as well as the airport wind speed records during the monitored periods. Another annual courtyard microclimate weather file was prepared using this weather file as an input for the calibrated FD courtyard microclimate model.

4.1 Case Study Courtyard House

4.1.1 Survey of the Courtyard Houses

An overall evaluation was made among traditional courtyard houses of Old Cairo to select one for thermal monitoring. On-site reviews were made for 9 candidate Cairene courtyard houses (see Appendix (B)). The 'Zeynab Khatun' courtyard house was selected and thermal monitoring began on August 4, 2001.

4.1.2 The Case Study Courtyard House

The "Zeynab Khatun" (Lady Zeynab) traditional courtyard house (~1400AD) was selected among a set of the remaining original traditional courtyard houses (25 houses) of old Cairo as a case study for field thermal monitoring. The restored house includes some features that are common in traditional Cairene courtyard houses: high thermal mass, wooden lattice window shades, shutter-less windows, high ceilings, marble floors, wall cladding, and dome vents.

The house dates back before 1468 A.D. Building materials are limestone, marble and wood. The land lot that contains the house is approximately a square lot shaped oriented at 25 degrees east of the north. The house has one of its exterior walls on a short alley, and the other is part of an intersection of three alleys. The other two sides used to have attached neighbor buildings, which have been demolished, making it a free standing building, that is now fully exposed to an open yard (of the current neighbor Al-Azhar University campus, continuously open since ~975A.D.).

The house currently has two secondary courtyards besides the main courtyard (Figure 4.1): the kitchen and the service courtyards. The main courtyard used to have a fountain which is currently buried under its pavement. Living spaces concentrate on the South West and the North West wings of the house (orientation denotes the wing's facade onto the main courtyard). A winter hall and a summer hall are in each wing respectively, referring to seasonal migrations within the house. The southeast wing falls between the three courtyards, and includes the reception hall at its ground floor, which was the internal space used for comparing the monitored versus DOE-2 simulated hourly dry bulb temperatures. It showed an overall cooler thermal record than similar spaces at the upper floor. The Reception hall is placed between the main courtyard (large) and the service courtyard (small). This kind of arrangement of spaces generated a constant airflow pattern of breezes between both courtyards through the reception hall, which makes it most affected by the courtyard microclimates. This airflow pattern was observed during the measurement period and video taped. The third wing is composed mainly of the main entrance, above which there is the customary large terrace found in such houses that faces the summer winds (northeast), and a fourth narrow wing that used to have a few secondary rooms. Figure 4.1 includes a plan and a section of the case study house, showing the placement of the monitoring sensors. Of particular interest to the current research are the sensors in the main courtyard, reception hall and rooftop. Further description of the case study house and its special characteristics as

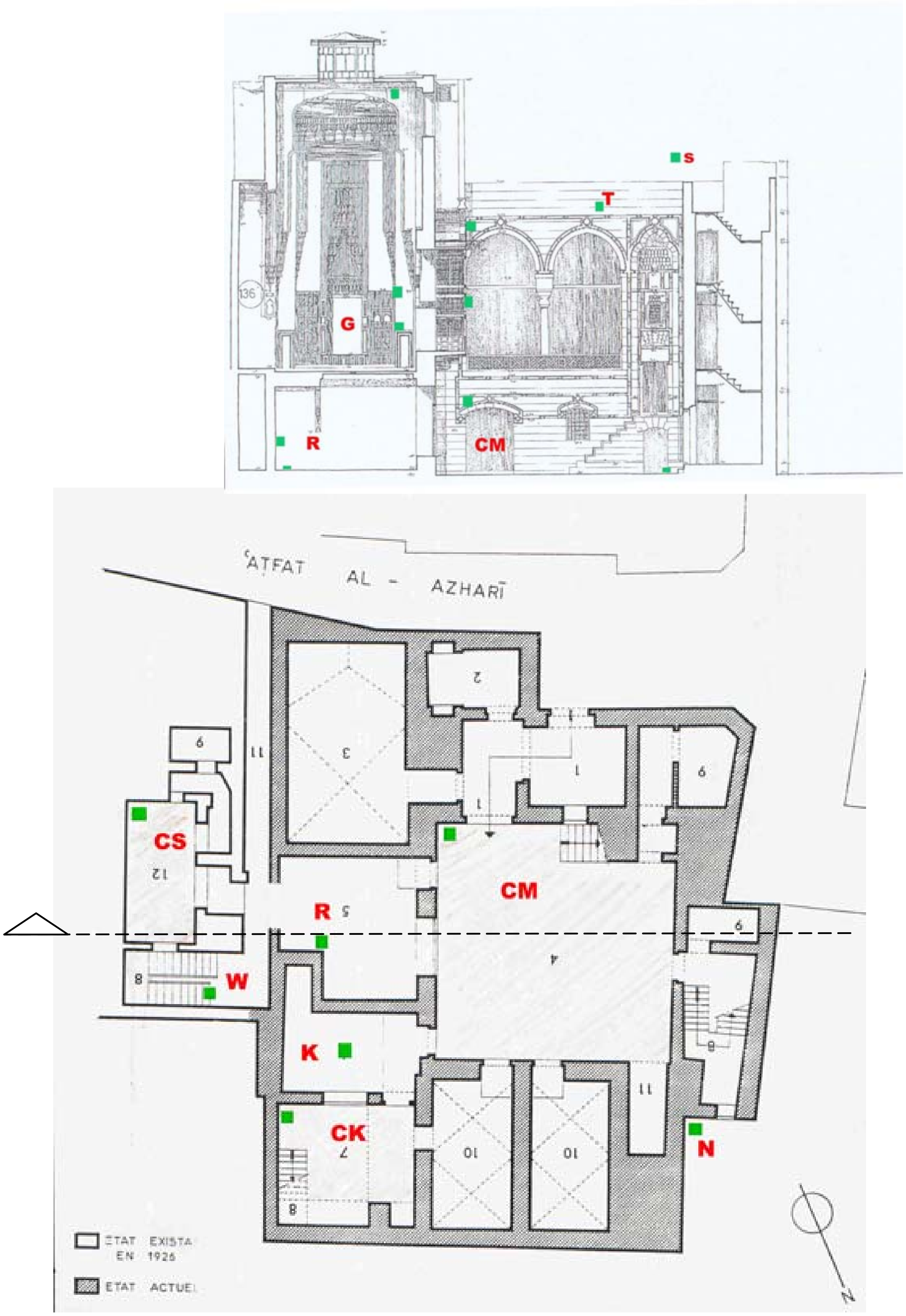


Figure 4.1 Ground Floor Plan & Section of the Case Study House.
Spaces: Main courtyard (CM), Service courtyard (CS), Kitchen courtyard (CK), Reception hall (R), summer hall (G), Rooftop solar Radiation shield (S). Note the places of the monitoring sensors in the main courtyard (CM), reception hall (R) & rooftop (S). Little square marks are the places of the sensors.

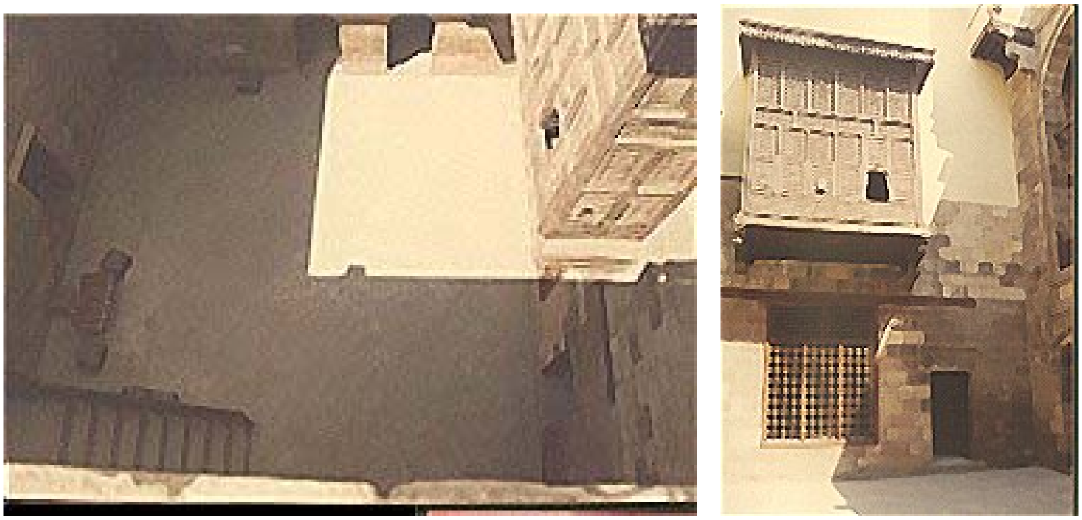


Figure 4.2 Photo of the Main Courtyard Floor with a Photo of the Courtyard North-facing Corner Where Monitoring Sensors Were Placed at the Heights of 10 & 20 ft.

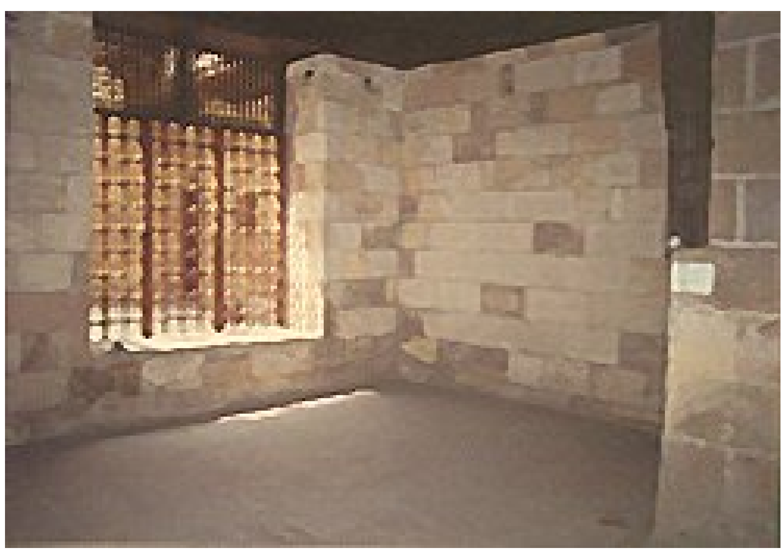


Figure 4.3 DB/RH Hobo Was Placed at a Height of 5 ft. Inside the Reception Hall Opening onto the Main Courtyard at the Ground Floor.

related to the thermal mass that may be considered in the thermal simulation are listed in Appendix C.

4.1.3 Operating Schedules

The house is open to the public as a tourism monument. Its entry gate operating schedule is from 9 a.m. to 10 p.m. year round. As the entry gate was only open during the operating hours, this schedule was applied in DOE-2 to the airflow between the courtyard and the street that occurs through the gate. The house has no air conditioning system. There are two employees for ticketing and guiding tourists in addition to two workers for cleaning the house. The number of visitors to the house is low with an estimated average occupancy of one person per space during the hours it is open.

4.2 Measurements and Data Collection

4.2.1 Cairo Weather Data

The ambient weather data collected from Cairo during the summer of 2001 and the winter of 2002 were obtained from two sources:

a) The Central Laboratory for Agricultural Climatology (CLAC) which is located in Giza about 15 miles south east from the house, and

b) The Cairo International Airport which is located about 10 miles northeast of the house.

Onsite measurements included rooftop dry-bulb temperature and relative humidity. These were measured using ‘Onset’ micro data-loggers (Onset 2002) that were first calibrated then placed in an ‘Onset’ Solar Radiation Shield that also provides rain protection. The weather data obtained from the Central Laboratory for Agricultural Climatology (CLAC) included: 1) dry-bulb temperature, 2) dew-point temperature, 3) global horizontal solar radiation, and 4) ground temperature. The weather data for Cairo International Airport were copied on daily basis from the National Weather Service NWS, National Oceanic and Atmospheric Administration (NOAA) website, published for each hour. These data included: 1) barometric pressure, 2) dry-bulb temperature, 3) dew-point temperature, 4) wind speed and direction. Unlike the weather obtained from the CLAC, the weather obtained from the NWS website was missing data for about 11%

of the summer monitoring hours and 34% of the winter monitoring hours. Thus the CLAC data were considered to be the primary weather source.

4.2.2 Instrumentation and Calibration

Figure 4.2 shows the placement of the sensors inside the courtyard house and Figure 4.3 shows one of the portable temperature/relative humidity sensors placed inside the reception hall. The indoor air temperature, relative humidity, and floor surface temperature were measured using micro data-loggers (Onset, 2002). The measurements included: 1) indoor air temperature and relative humidity inside the reception hall at the ground floor level, 2) indoor air temperature and relative humidity at the grand hall and winter hall at the first floor level, 3) the air temperature and relative humidity at the heights of 10 ft. and 20 ft. at the main courtyard besides the courtyard floor temperature [surface temperatures were obtained by attaching a sensor to the surface and covering it with a 3inch wide x 3 inch long x 2 inch thick piece of foam] , and 4) the air temperature and relative humidity at the rooftop. Data-loggers were calibrated before being deployed at the site, and they were recalibrated after the measurements were completed.

4.3 Calibrated DOE-2/FD Model Simulations

To perform this study, the DOE-2.1e building simulation program was used (LBNL 1994; 2001) with a finite difference thermal network simulation of the courtyard microclimate. The DOE-2 program was chosen because of its ability to simulate the overall thermal performance of a building using specially prepared hourly weather files that contained Cairo weather data during the monitoring periods for the case study courtyard house. The resulting simulated temperatures from the DOE-2 simulation for the "reception hall" at the ground floor were compared against monitored temperature data. A finite difference thermal network simulation for the courtyard microclimate was created and then calibrated to the measured data from the 21 days summer period, and the 21 days winter period. This FD model of the courtyard microclimate was then used to predict one year of hourly data for the courtyard using the IWEC weather file with rooftop temperature records. This synthetic annual courtyard conditions was then used with the DOE-2 simulation of the interior zone, to obtain an improved simulation.

4.3.1 DOE-2 Thermal Simulations

The DOE-2 program, developed by the Lawrence Berkeley National Laboratory, is an hourly thermal simulation program used to calculate multi-zone envelope, system, and plant heating and cooling loads. This public-domain simulation program allows users to perform hourly building energy simulations for a one-year period using ASHRAE algorithms. The heat transfer by conduction and radiation through the walls, roofs, floors, windows, and doors are calculated separately using response factors.

4.3.1.1 DOE-2 Analyses of Unconditioned Buildings

DOE-2 was primarily designed to help building designers perform annual calculations of energy consumed by various heating and cooling systems. However, this research is concerned with the case study courtyard house that belongs to the set of heavy thermal mass buildings with no heating, ventilating, or air-conditioning (HVAC) systems. Therefore, special procedures were used in modeling the case study courtyard house in DOE-2:

4.3.1.1.1 DOE-2 Weighting Factor Method

DOE-2 employs weighting factors for the calculation of thermal loads and room air temperatures. With the weighting factor method, hourly thermal-load calculation is performed based on a physical description of the building and that hour's ambient weather conditions. These loads are used, along with the characteristics and availability of heating or cooling systems for the building, to calculate air temperatures and the heat extraction or heat addition rates.

In the DOE-2 program the user must use one of the following two weighing factor methods:

1. Precalculated ASHRAE weighting factors used in DOE-2 for typical constructions. The only parameter that varies is the combined weight of floors, walls, and furniture, which is the effective thermal mass of the space. To use this option, it is necessary to use the appropriate value for the

FLOOR-WEIGHT keyword. These weighting factors produce the least accurate results.

2. Custom Weighting Factors are a set of heat-gain and air-temperature weighting factors that are calculated by DOE-2 for a particular room using an actual description of the room for the calculation.

   The use of Custom Weighting Factors is recommended for the following cases:

   - Passive solar buildings
   - Heavy weight masonry buildings or other buildings with heavy construction.
   - Building located in sunny locations with large amounts of solar energy entering the spaces.
   - Any building in which it is necessary to define the solar distribution of the solar radiation within the building.

The case study courtyard house is a masonry building made up of heavy thermal mass with no furniture. Thus Custom Weighting Factors were applied for the case study house simulation in the DOE-2 program. The custom weighting factors were automatically calculated for each space by setting the FLOOR-WEIGHT = 0 in all SPACE-CONDITIONS.

4.3.1.1.2 Openings of the Case Study House and Their Modeling in DOE-2

The overall heat gain from solar radiation through the openings in the case study courtyard house was expected not to be significant due to the small window/wall ratio. The house is composed mainly of four wings around a main square courtyard. Two of these wings include the indoor living spaces. The other two includes the entry vestibule, terrace, storage rooms …etc. Two other smaller courtyards are located at the perimeter of the house. The largest window/wall ratios in the case study house are onto the main courtyard, which is the main outdoor space. The window/wall ratio for the southwest facing wing (winter hall and roof suite) is 23%, and for the northwest facing wing (summer hall and reception hall) is 20%. All windows are behind wooden screens.

The following is a summary of the simulation modeling concepts for the types of openings of the case study house:

1. Windows having an external wooden screen with a single glass pane: Some windows in the case study house are backed with newly-added single glass leaves (glass panes were not present in architectural practice at the time when the house was built). The wooden screens are of two main grid sizes measured from detailed drawings by (Waziri, 1998):

   - Wide (6.5"x 6.5"x 1"deep) having ratio solid/void area = 0.34
   - Narrow (~0.5"x 0.5"x 0.5"deep) having a ratio of solid/void area = 0.50

   These wooden grid screens were modeled in DOE-2 with the following considerations:

   - Conductance: the material of the wood frame was included in the window frame material. The wood screens were calculated and found to cover about 50% of the window area in case of a narrow grid and about 34% of the window area in case of a wide grid. In the DOE-2 simulation, a window frame needs to be entered with its coordinates different from the glazing coordinates in case its area is over 10% of the window area, which applies to such windows.

   - Shades were applied to windows with narrow screens with a transmittance value of 0.5 and to windows with wide screens with a transmittance of 0.65. These transmittance values reflected the solid/ void ratio of the screens. Both screens had a constant schedule value of 1 for the year. (In reality, these wooden screens posses a varying transmittance shading-schedule, as well as a sky-form-factor. Yet applying detailed modeling (i.e., having maximum shading around noon) is beyond the scope of this work).

2. Windows having an external wooden grid screen with no glass panes: There are two windows of this type, and both open onto courtyards on the ground floor level. The direct solar radiation gain through these two windows is not significant since both are opening at the courtyard ground floor level, being shaded most of the day by the courtyard walls. One of these windows faces northeast and therefore receives no

direct solar radiation. The second is facing north west. This would downplay the role of solar gain from such windows which would have been otherwise simulated by calculating the solar radiation falling on the window panes and to feed this as heat gain to the space.

3. Windows made of gypsum and thick colored glass pieces: In DOE-2, this was modeled as door by making a composite material having weighted properties of gypsum and glass. The effect of the solar radiation transmittance was not considered as the glass was thick (>2") and occupied a small portion of the window, as it served mainly for decorative purposes.
4. Other openings: wooden doors (solid wood), wooden windows (solid wood), and windows of fixed glass panes with wooden frames were modeled as described.

4.3.1.1.3 Underground Surface Modeling in DOE-2

The case study courtyard house is earth sheltered 3.3 ft. (1 m.) below its entry level. This means that the underground portions of the walls at the perimeter of the house, as well as the ground floor slab need to be modeled as underground surfaces. In modeling these surfaces, the procedures described by Winkelmann (1998) for determining the effective construction for an underground surface that properly accounts for its thermal mass were used. Due to the unusual thickness of the walls (up to 3 ft.) at the ground floor for the courtyard house, the proposed effective construction calculations were not applicable (producing negative numbers). Even for the 1.3 ft. wall thickness the effective construction still produced negative numbers. Yet, the effective construction calculations worked fine for the floors, while that for the walls were not applied.

4.3.1.2 Processing a DOE-2 Weather File Using the Cairo Weather Data

Figure 4.4 shows a flowchart diagram for the DOE-2 weather processing. The DOE-2 program was designed to calculate hourly building energy consumptions by using hourly weather data available in several file formats. The available types of weather files include the Test Reference Year (TRY and TRY2), the Typical Meteorological Year (TMY and TMY2), the California Climate Zone (CTZ), and the Weather Year for Energy Consumption (WYEC and WYEC2). However, before the DOE-2 simulation program can execute, users need to convert ASCII files into binary files recognizable by DOE-2. Recently, the Lawrence Berkeley National Laboratory (LBNL) developed a sub-program, that converts an ASCII file into binary files. It is called the "DOE-2 weather processor" (LBNL 2001), or commonly known as the "DOE-2 Weather Packer."

To pack the actual Cairo weather data into a DOE-2 weather file, the hourly weather data from Cairo must be in the TRY, TMY, TMY2, CTZ, or WYEC file formats. Since the TRY format contains all the data necessary for this research, this format was used to pack the Cairo weather data into a DOE-2 weather file. The flowchart diagram in Figure 4.4 demonstrates how the raw hourly weather data for the monitoring periods obtained from the Central Laboratory for Agricultural Climate (CLAC) (DB, RH & global horizontal solar radiation) and from Cairo International Airport (wind speed & direction) for the same period were converted into the TRY file needed by the DOE-2 weather packer. Wind data were not available for some hours (11% of the summer and 34% of the winter) monitoring periods and was completed by copying the wind data records of the previous day.

4.3.1.2.1 Synthesizing Global Horizontal Radiation into Beam and Diffuse Components

The global horizontal solar radiation was synthesized into the beam and diffuse components (Figure 4.5) using the correlations developed by Erbs et al. (1982) according to the following formulas:

$$\frac{I_{dif}}{I_{glo}} = 1.0 - 0.09k_T \qquad \text{for } 0 \;\; k_T \le 0.22 \qquad (4.1)$$

$$\frac{I_{dif}}{I_{glo}} = 0.9511 - 0.1604k_T + 4.388k_T^2 - 16.638k_T^3 + 12.336k_T^4 \qquad \text{for } 0.22 < k_T \le 0.80 \qquad (4.2)$$

$$\frac{I_{dif}}{I_{glo}} = 0.165 \qquad \text{for } 0.80 < k_T \qquad (4.3)$$

Where I_{dif} is the diffuse solar radiation, I_{glo} is the global horizontal solar radiation, and k_T is the hourly clearness index (i.e., the ratio of terrestrial and extraterrestrial solar radiation), which was calculated by the following formula:

$$k_T = \frac{I_{glo}}{I_0} \tag{4.4}$$

Where θ_S is the zenith angle of the sun, which is the incidence angle on the horizontal surfaces; I_0 is the extraterrestrial solar radiation that would be received in the absence of atmosphere on a horizontal surface at the same latitude, longitude, and time of the year (Duffie and Beckman, 1991), which was calculated using the following formula:

$$I_0 = I_{SC}\left(1 + 0.033\cos\frac{360^\circ \times n}{365}\right) \times \cos\theta_Z \quad \text{Btu/ (h} \cdot \text{ft.}^2\text{)} \tag{4.5}$$

with the solar constant I_{SC} = 432 Btu/ft.^{2} hr (= 1367 W/m^2), ϕ is the latitude for Cairo, ω is the hour angle, and δ is the solar declination, and n is the day of year (e.g., $n = 1$ for January 1).

For horizontal surfaces, the angle of incidence is the zenith angle of the sun θ_z, where:

$$\text{Cos}\ \theta_z = \cos\phi \cos\delta \cos\omega + \sin\phi \sin\delta \tag{4.6}$$

The hour angle and the solar declination were calculated according to the following formulas:

$$\omega = (\text{solar time-12}) \text{ x } 15 \tag{4.7}$$

$$\delta = 23.45 \sin (((360\ (284+n))/365)) \tag{4.8}$$

The direct beam radiation on a surface normal to the radiation may be calculated from the direct beam radiation on a horizontal surface by using the geometric factor R_b; the ratio of beam radiation on a tilted surface to that on a horizontal surface.

$$R_b = \frac{\cos\theta}{\cos\theta_z} \tag{4.9}$$

= direct beam normal radiation / direct beam radiation on a horizontal surface

In this case $\theta = 0$, thus

Direct beam normal radiation = beam radiation on a horizontal surface x $(1/\cos\theta_z)$

Once a Cairo TRY file was prepared, the DOE-2 Weather Packer converted this TRY file into a binary file that DOE-2 could read.

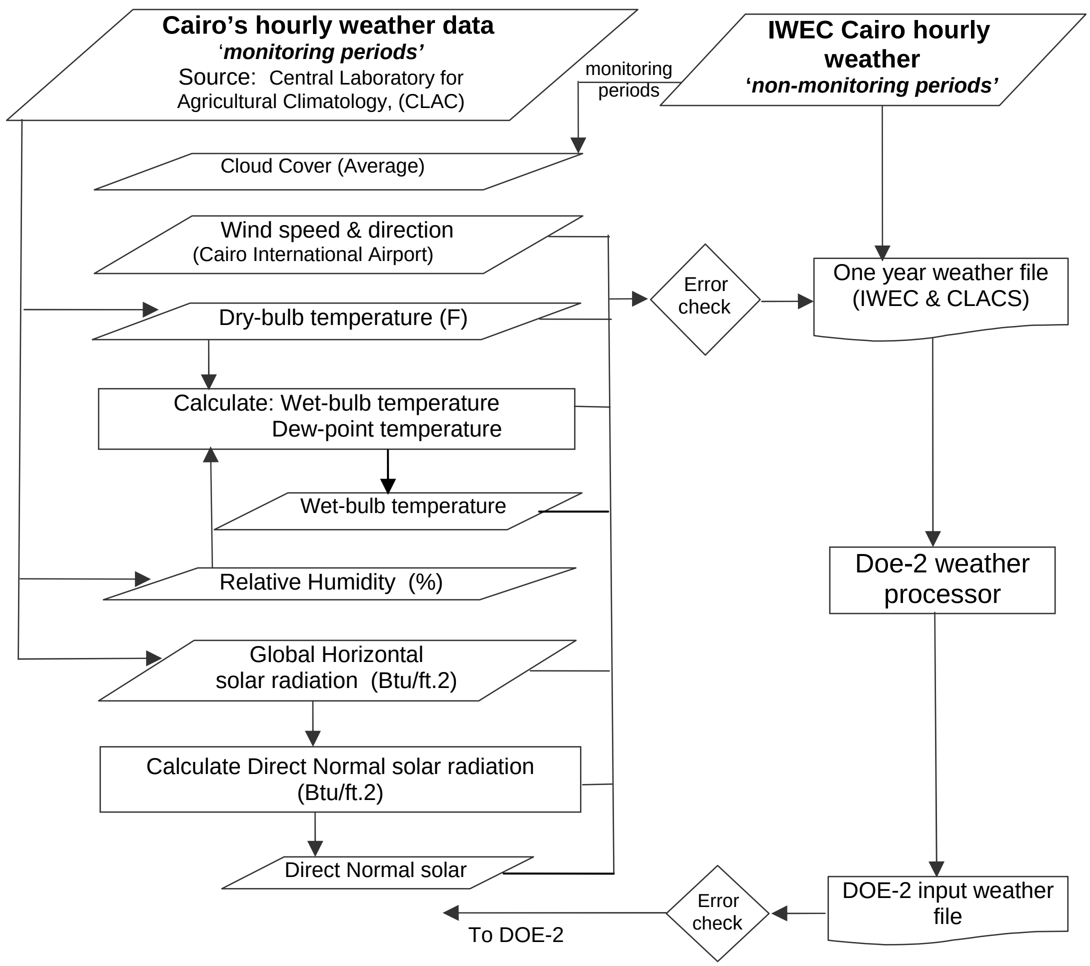


Figure 4.4 The DOE-2 Weather Data Processing.

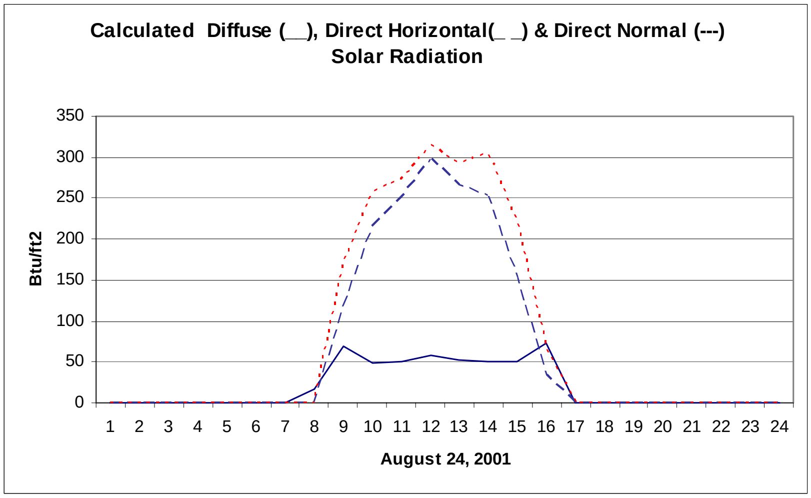


Figure 4.5 Sample Calculated Solar Components for a Clear Day.

4.3.1.3 Creating a DOE-2 Input File to Simulate the Courtyard House

Current building thermal simulation programs (like DOE-2) simulate a building in the limited terms of a single weather file, one-dimensional thermal mass and orientation, and the representation of airflow in terms of air change per hour (ACH) in or out of a zone. These limitations in thermal modeling do allow for the modeling of an abstract courtyard house based on the original courtyard house for the purpose of facilitating computer simulations.

Therefore an abstract model was developed that combined the two secondary courtyards into the main courtyard for producing one courtyard (to be modeled with the microclimate weather file), surrounded by an envelope with similar characteristics to the original house. The abstract model is similar to the original case study in: shape and orientation, spatial volumes, and windows areas and orientations. Although courtyard surface areas in the abstract model were less than the sum of the surface areas of the three original courtyards, the volume of the abstract courtyard is equal to that of the combined volume for the three original courtyards.

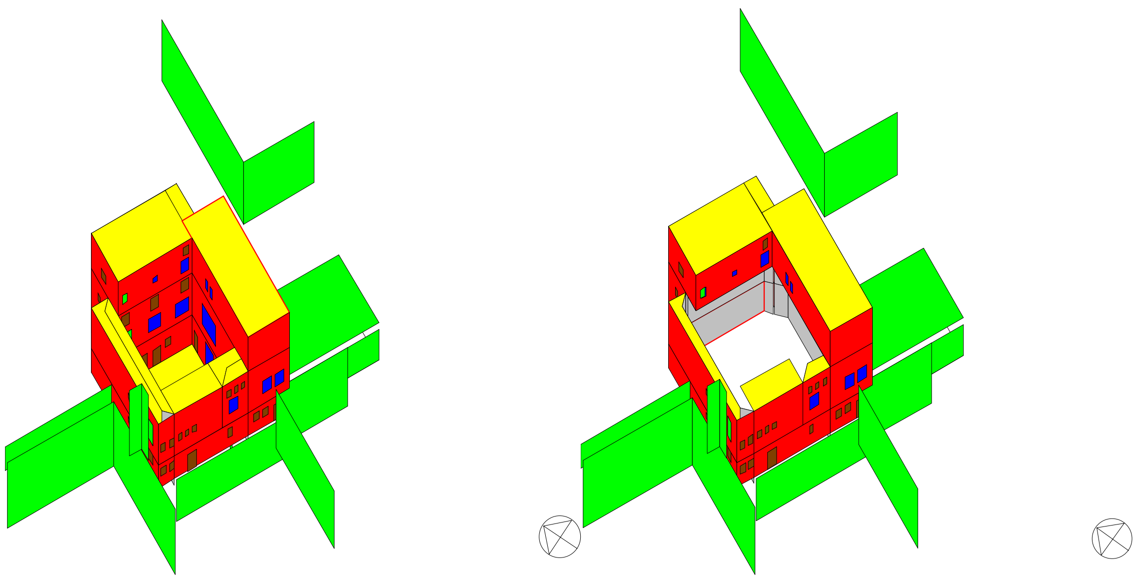
The abstract model was then used to simulate the courtyard house by splitting it into two rings of zones: an inner ring of zones affected by the courtyard microclimate weather file and an outer ring of zones affected by the ambient weather file. Both inner ring and outer ring of zones in the simulation runs are either separated with a standard or an adiabatic interior wall having no thermal exchange. The accuracy of the DOE-2 simulation runs for the courtyard house will be investigated through validation against measured data from the case study house that was recorded during the summer and winter monitoring periods at the reception hall space located in the ground floor.

The standard base case run considers the ambient weather file (i.e., IWEC data) affecting the entire envelope of the house (i.e., the interior courtyard walls and exterior building walls). In the base case simulation of a courtyard house, the DOE-2 program will use the ambient weather file for both the courtyard as well as the exterior envelope of the house, thus ignoring the courtyard microclimate. Another site-related base case run was made that considers the ambient weather file (i.e., IWEC data) augmented with rooftop weather data for the monitoring periods affecting the entire envelope of the house (i.e., the interior courtyard walls and exterior building walls).

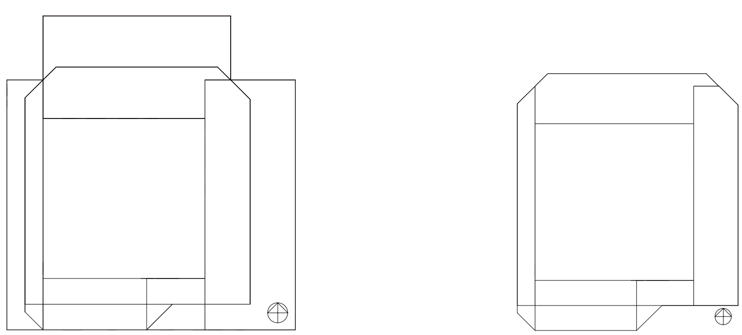
In the current research, an FD model will be used to generate a courtyard microclimate weather file to be used in the DOE-2 simulation. For the second set of simulations, the house was divided into two sets of zones: an inner ring of zones affected by the courtyard microclimate weather file and an outer ring of zones affected by the ambient weather file. Two separate runs were made: the first run considers the ambient weather file with the outer ring of zones having its exterior envelope and outer zones affected by it, while adiabatic interior walls having no thermal exchange were used to separate it from the inner ring of zones.

The output hourly temperatures from the first run were reduced to monthly average temperatures used as the indoor set-point for air-conditioned outer zones adjacent to the inner ring of zones in the second run that uses the courtyard's microclimate weather file with the internal ring of zones having its exterior envelope and interior zones (including the reception hall) affected by it.

The results from this research allow for the comparison of a standard DOE-2 simulation for the courtyard house against a simulation that includes a courtyard microclimate weather files for the configuration that represents the case study courtyard house. Figure 4.6 shows conceptual images of the case study house in the DOE-2 simulation input files using the DrawBDL program, and Table 4.2 lays out the courtyard house simulations' details (purpose, simulated building, building zones, and weather file) and order.



a) Isometric illustrations showing the house with and without the inner zone



b) Wire site plan illustration for both the house and the inner zone.

Figure 4.6 Conceptual Images of the Case Study House DOE-2 Simulation Input Using the DrawBDL Program.

Table 4.2 Courtyard House Simulation Details and Order.

Simulation	*Purpose*	*Simulated Building*	*Building zones*				*Weather file*	
			Outer zones ring (zone type)	*Interior wall between inner & outer rings* (wall type)	*Inner zones ring* (zone type)	*AC box* (fictitious isolated zone)	*Monitoring periods* (Aug. 2001, Dec. 2001 & Jan. 2002.)	*Annual - without monitoring periods*
1	*Base case (Standard)*	*Whole house*	*Unconditioned*	*Standard*	*Unconditioned*	*Conditioned*	*IWEC*	*IWEC*
2	*Base case (Site related)*	*Whole house*	*Unconditioned*	*Standard*	*Unconditioned*	*Conditioned*	*Rooftop (DB&WB), CLAC (solar, GT), Airport (wind)*	*IWEC*
3.1	*Simulate temperatures in outer zones ring using rooftop weather file*	*Outer zones only*	*Unconditioned*	*Adiabatic*	*Omitted*	*Conditioned*	*Rooftop (DB&WB), CLAC (solar, GT), Airport (wind)*	*IWEC*
3.2	*Simulate temperatures in inner zones ring using courtyard weather file*	*Whole house*	*Conditioned (from simulation #3.1; average temperatures using rooftop weather file)*	*Standard*	*Unconditioned*	*Conditioned*	*Courtyard microclimate (DB&WB), CLAC (solar, GT), Airport (wind)*	*Courtyard simulated microclimate (DB&WB), CLAC (solar, GT), Airport (wind)*

4.3.2 Courtyard Microclimate Weather File

This research will create a courtyard microclimate weather file simulation based on an RC thermal network model. The courtyard microclimate RC thermal model will be calibrated against field data from the case study house. The model will then be used to produce annual hourly courtyard weather file to be incorporated with the thermal simulation of the case study courtyard house in the DOE-2 program

4.3.2.1 Finite Difference (FD) Model

The finite difference (FD) method is widely used as a solution for transient heat transfer problems. The method applied here uses the explicit method where the temperature of any node at a new time $t+1$ is calculated from the temperature at the same node and neighboring nodes for the previous time t.

4.3.2.2 Application of the FD Model for the Thermal Analyses of the Courtyard Microclimate

Figure 4.7 shows the Finite Difference (FD) equivalent thermal circuit for the case study courtyard house. The house is represented using two lumped wall nodes facing north and south, with air nodes in between the walls. The north wall nodes represent the NE & NW wings of the house while the south wall nodes represent the SE & SW wings of the courtyard house up to the height of the main courtyard (i.e., two floors). The mass and the width of each of the north and south wall nodes were calculated respectively with the consideration of dividing the case study courtyard house into two zones: north and south. The courtyard house being approximately square shaped oriented 25 degrees east of north allowed to easily divide the house into a north zone composed of its north west and north east wings and a south zone composed of its south east and south west wings. Data about the thermal mass and the average thermal properties for each of the two walls were calculated from the respective zones in the case study house. The nominal face area of the wall nodes represents the equivalent area of the walls in the main courtyard of the case study house.

The courtyard was divided into two sections: lower and upper, that corresponds to the temperature measurements taken on site. Each section contains at its center an air node for the thermal heat balance. Each air node has natural convection with the ambient air: the upper node communicates with the upper courtyard ambient air node, and the lower node communicates with the street ambient air node (through the house entry gate), and also communicates with the lumped ground node. Each air node in the lower or upper courtyard sections also have convection exchange with the other nodes on the courtyard envelope as indicated in Figure 4.7.

One-dimensional thermal mass walls were used to simplify the analyses, and parametric sensitivity studies were used to solve for the equivalent thermal properties. The equations for each node were developed using an energy balance. All the internal nodes have material of width ($\Delta x/4$) associated with them on either side of their center plane, and the boundary nodes have material of width ($\Delta x/4$). The temperature at the surface nodes was calculated considering solar radiation, natural convection, conduction, and sky radiation. Radiation between the courtyard envelope surfaces was ignored as its effect on the resulting courtyard air temperature is insignificant compared to the rest of the thermal reactions considered. The temperatures for the nodes inside the wall or in the ground nodes were calculated using conduction only. The temperatures for the ambient air and the ground were assigned from climatic records. The simulated air temperature for the two nodes inside the courtyard (upper and lower) were compared to field measurements in order to calibrate the model.

Table 4.3 includes a list of the heat balance equations for each node along with their stability criteria.

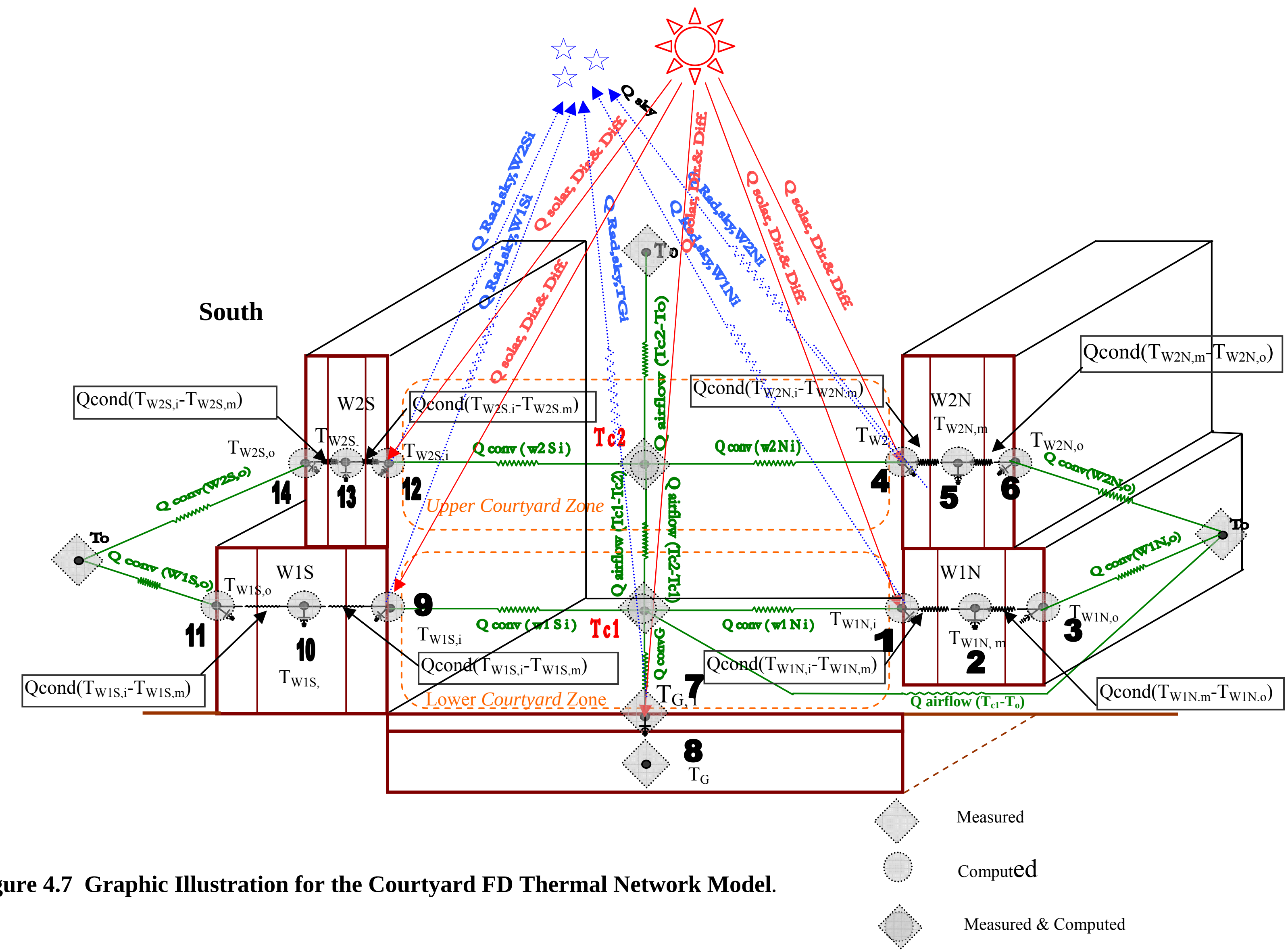


Figure 4.7 Graphic Illustration for the Courtyard FD Thermal Network Model.

Table 4.3 Finite Difference Model Equations.

	Equations	Stability Criteria [1]
A I R	**Node T_{c1}** $T^p_{c1} = (h_g A_g (T^p_{Gi}) + h_{W1N} A_{W1N} (T^p_{W1Ni}) + h_{W1S} A_{W1S} (T^p_{W1Si}) + m_{air(To-Tci)} \times C_{p\,air} \times (T^p o) + m_{air\,(Tc2-Tc1)} \times C_{p\,air} \times (T^p_{c2})) / (h_{W1N} A_{W1N} + h_{W1S} A_{W1S} + h_g A_g + m_{air(To-Tc1)} \times C_{p\,air} + m_{air(Tc2-Tc1)} \times C_{p\,air})$ **Node T_{c2}** $T^p_{c2} = (m_{air\,(Tc1-Tc2)} \times C_{p\,air} \times (T^p_{c1}) + m_{air\,(To-Tc2)} \times C_{p\,air} \times (T^p_o) + h_{W2N} A_{W2N} (T^p_{W2Ni}) + h_{W2S} A_{W2S} (T^p_{W2Si})) / (m_{air\,(Tc1-Tc2)} \times C_{p\,air} + m_{air\,(To-Tc2)} \times C_{p\,air} + h_{W2N} A_{W2N} + h_{W2S} A_{W2S})$	
W A L L S	**Node $T_{W1N,i}$** ***# 1,4,9,12*** $T^{p+1}_{WINi} = T^{p}_{WINi}\,(1-2\,Fo\,(B_i+1)) + 2\,Fo\,T^p_{W1N,m} + 2\,B_i\,Fo\,T^p_{c1} + (Q_{solar} + Q_{sky,\,W1N}) / \left(\rho_{W1N} C_{p,W1N} A_{W1N} \frac{\Delta_x}{2\Delta t}\right)$	$\Delta_t \le \dfrac{\rho_{W1N} C_{p,W1N} \Delta_X^2}{2K_{avg}(B+1)}$
	Node $T_{W1N,m}$ ***# 5,2,13,10*** $T^{p+1}_{WIN,m} = T^p_{W1N,m}\,(1-2\,Fo) + F_O\,T^p_{W1N,i} + Fo\,T^p_{W1N,o}$	$\Delta_t \le \dfrac{\rho_{W1N} C_{p,W1N} \Delta_X^2}{2K_{avg}}$
	Node $T_{W1N,o}$ ***# 3,6,11,14*** $T^{p+1}_{WIN,o} = T^{p}_{W1N,o}\,(1-2\,Fo\,(B_i+1)) + 2\,Fo\,T^P_{W1N,m} + 2\,B_i\,Fo\,T^P_O$	$\Delta_t \le \dfrac{\rho_{W1N} C_{p,W1N} \Delta_X^2}{2K_{avg}(B+1)}$
G R O U N D	**Node $T_{G,i}$** ***# 7*** $T^{p+1}_{G,i} = T^{p}_{G,i}\,(1\,.2\,Fo\,(B_i+1)) + 2\,Fo\,T^p_{G,m} + 2\,B_i\,Fo\,T^p_{c1} + ((Q_{solar} + Q_{sky,\,G,i}) / \left(\rho_G\, Cp_{,G}\, A_G \frac{\Delta_x}{2\Delta t}\right))$	$\Delta_t \le \dfrac{\rho_{W1N} C_{p,W1N} \Delta_X^2}{2K_{avg}(B+1)}$

Biot[2] (**B**$_i$) and Fourier[3] (**F**o) numbers were used to simplify the expressions:

$$B_i = (h_{W1N}\,\Delta x) / k_{avg} \qquad Fo = \frac{K_{avg}\Delta t}{\rho_{W1N} C_{P,W1N} \Delta_x^2} \qquad B_i\,Fo = \frac{h_{W1N}\Delta t}{\rho_{W1N} C_{p,W1N} \Delta_X}$$

1. To prevent unstable results *t* must remain within the stability limit. To satisfy the stability criterion in a case of one-dimensional transient conduction, the value of *t* should be determined as the minimum number among the calculated delta t values for the nodes (or any time step less than this) which would satisfy the given conditions.
2. The Biot number is a dimensionless measurement of the temperature change in the solid relative to the temperature difference between the surface and fluid.
3. The Fourier number is a dimensionless time parameter that characterizes transient conduction heat transfer.

4.3.2.3 Description for the Nodal Energy Balance Formulas

4.3.2.3.1 The Courtyard Lower Air Node, T_{c1}

From the energy balance at the courtyard lower air node (T_{c1}), the total heat transfer between the courtyard lower air node and the street ambient air node T_o, as well as the courtyard upper air node T_{c2}, is equal to the convection heat transfer between the courtyard lower air node with the courtyard walls and ground. The equation of the energy balance at this node is given by

$$Q_{\text{airflow (To -Tc1)}} + Q_{\text{airflow (Tc2-Tc1))}} = Q_{\text{conv (G)}} + Q_{\text{conv (W1N i)}} + Q_{\text{conv (W1S i)}} \quad (4.10)$$

In the finite difference method of dynamic heat transfer calculation time t (hr) is given by:

$$T = p\Delta t \quad (4.11)$$

Where t is the hourly interval time for the heat conduction, p is an integer introduced to discretize or approximate the hourly time t into t time steps for the finite difference approximations of the dynamic heat transfer equation.

Using the explicit finite difference solution scheme yields

$$m_{\text{air (To-Tc1)}} \text{ x } C_{p\text{ air}} \text{ x } (T^p{}_{c1}-T^p o) + m_{\text{air (Tc2-Tc1)}} \text{ x } C_{p\text{ air}} \text{ x } (T^p{}_{c1}-T^p{}_{c2}) = h_g A_g (T^p{}_{Gi}-T^p{}_{c1}) + h_{W1N} A_{W1N} (T^p{}_{W1Ni}- T^p{}_{c1}) + h_{W1S} A_{W1S} (T^p{}_{W1Si}- T^p{}_{c1}) \quad (4.12)$$

Where $T^p{}_{c1}$ is the temperature at the courtyard lower air node at time p, $T^p{}_{c2}$ is the temperature at the courtyard upper air node, $T^p{}_o$ is the ambient temperature at the street, $T^p{}_{W1Si}$ & $T^p{}_{W1Ni}$ are the temperatures of the courtyard wall lower section, and $T^p{}_{Gi}$ is the courtyard ground temperature. The value of h_g is the fixed convection coefficient between the courtyard lower node and the courtyard floor, and h_{W1N} & h_{W1S} are the constant convection coefficients between the courtyard lower node and the courtyard wall lower sections.

Solving the expression for the courtyard lower air node temperature $T^p{}_{c1}$, yields

$$T^{p}_{c1} = (h_g A_g (T^{p}_{Gi}) + h_{W1N} A_{W1N} (T^{p}_{W1Ni}) + h_{W1S} A_{W1S} (T^{p}_{W1Si}) + m_{air(To-Tci)} \times C_{p\,air} \times (T^{p}o) + m_{air\,(Tc2-Tc1)} \times C_{p\,air} \times (T^{p}_{c2})) / (h_{W1N} A_{W1N} + h_{W1S} A_{W1S} + h_g A_g + m_{air(To-Tc1)} \times C_{p\,air} + m_{air(Tc2-Tc1)} \times C_{p\,air}) \tag{4.13}$$

Where $m_{air(To-Tci)}$, $m_{air(Tc2-Tc1)}$ & $m_{air(To-Tc1)}$ are the volume flow rate (ACH) of air between the lower courtyard air node and the courtyard ground node, upper courtyard air node and street ambient air node respectively.

4.3.2.3.2 The Courtyard Upper Air Node, T_{c2}

Next, the temperature at the courtyard upper air node, T_{c2} can be calculated. The equation of the energy balance at this node is given by

$$Q_{airflow\,(Tc1-Tc2)} + Q_{airflow\,(To-Tc2)}^{TOP} = Q_{conv\,(W2Si)} + Q_{conv\,(W2Ni)} \tag{4.14}$$

The explicit finite difference expression for this heat transfer is

$$m_{air\,(Tc1-Tc2)} \times C_{p\,air} \times (-T^{p}_{c1}+T^{p}_{c2}) + m_{air\,(To-Tc2)} \times C_{p\,air} \times (-T^{p}_{o} + T^{p}_{c2}) = h_{W2N} A_{W2N} (T^{p}_{W2Ni} - T^{p}_{c2}) + h_{W2S} A_{W2S} (T^{p}_{W2Si} - T^{p}_{c2}) \tag{4.15}$$

Where T^{p}_{c2} is the temperature at the courtyard upper air node at time p, T^{p}_{c1} is the temperature at the courtyard lower air node, T^{p}_{o} is the ambient temperature above the courtyard, and T^{p}_{W2Ni} & T^{p}_{W2Si} are the temperatures of the courtyard walls upper section. The values of h_{W2N} & h_{W2S} are the fixed convection coefficient between the courtyard upper node and the courtyard walls upper section.

Solving the expression for the courtyard upper air node temperature T^{p}_{c2}, yields

$$T^{p}_{c2} = (m_{air\,(Tc1-Tc2)} \times C_{p\,air} \times (T^{p}_{c1}) + m_{air\,(To-Tc2)} \times C_{p\,air} \times (T^{p}_{o}) + h_{W2N} A_{W2N} (T^{p}_{W2Ni}) + h_{W2S} A_{W2S} (T^{p}_{W2Si})) / (m_{air\,(Tc1-Tc2)} \times C_{p\,air} + m_{air\,(To-Tc2)} \times C_{p\,air} + h_{W2N} A_{W2N} + h_{W2S} A_{W2S}) \tag{4.16}$$

Where $m_{air\,(Tc1-Tc2)}$, $m_{air\,(Tc2-Tc1)}$ & $m_{air\,(To-Tc2)}$ are the airflow rates between the upper courtyard air node with the lower courtyard air node, the lower courtyard air node with the upper courtyard air node, and the upper courtyard air node with the above the courtyard ambient air node.

4.3.2.3.3 The Courtyard Wall Inside Surface Node, $T_{W1N,i}$

Next the temperature at the courtyard wall inside surface node, $T_{W1N,i}$ (nodes # 1, 4, 9 and 12) can be calculated. As the solar radiation falling on the wall surface heats up the wall, the long-sky radiation cools the wall, therefore the effects of the solar and sky radiations are considered for the energy balance calculations at the inside wall surface node $T_{W1N,i}$.

The equation of the energy balance at this node is given by

$$Q_{conv\,(W1N,i)} + Q_{solar(W1N\,i)} + Q_{rad,sky(W1N\,i)} + Q_{cond\,(}T_{W1N,m} - T_{W1N,i)} = Q_{store} \qquad (4.17)$$

The explicit finite difference expression for this heat transfer is

$$h_{W1N}\, A_{W1N}\, (T^{p}_{c1} - T^{p}_{W1Ni}) + (Q_{solar(W1N\,i)} + Q_{rad,sky(W1N\,i)}) + (k_{avg}\, Aw/\, \Delta_x)$$
$$(T^{p}_{W1N,m} - T^{p}_{W1N,i}) = \rho_{W1N}\, Cp,_{W1N}\, A_{W1N}\, (\Delta_x/2)\, \frac{(T^{p+1}_{W1N,i} - T^{p}_{W1N,i})}{\Delta t} \qquad (4.18)$$

Where $T_{W1N,i}$ is the temperature at the courtyard wall inside surface at time p, $T_{W1N,m}$ is the temperature at the wall middle node, T^{p}_{c1} is the courtyard lower node temperature, and T^{p}_{W2Ni} & T^{p}_{W2Si} are the temperatures of the courtyard walls upper section. k_{avg} is the weighted average value of the thermal conductivity of the wall materials, Aw is the wall surface area and Δ_x is ¼ of the wall thickness. The value of h_{W1N} is the constant convection coefficient between the courtyard lower air node and the courtyard wall inside surface.

Solving the expression for the courtyard wall inside surface node temperature T^{p+1}_{WINi}, which is the future temperature of the courtyard inside wall surface at the new time step (p+1) yields

T^{p+1}_{WINi} = T^{p}_{WINi} + (2 $h_{W1N}\Delta$t) (T^p_{c1} - T^p_{W1Ni}) / (ρ_{W1N} $Cp_{,W1N}$ Δ_x) +($T^p_{W1N,m}$ - $T^p_{W1N,i}$) (2 k_{avg} Δ t)/ (ρ_{W1N} $Cp_{,W1N}$ Δ_x^2) + (Q solar + Q sky) / (ρ_{W1N} $Cp_{,W1N}$ A_{W1N} $\frac{\Delta_x}{2\Delta t}$) (4.19)

By using the Biox number B_i = ($h_{W1N}\Delta$x) / k_{avg}, and the Fourier number $Fo = \dfrac{K_{avg}\Delta t}{\rho_{W1N} C_{P,W1`N} \Delta_x^2}$ to simplify the expression we get

T^{p+1}_{WINi} = T^{p}_{WINi} (1- 2 Fo(B_i +1)) + 2 B_i Fo T^p_{c1} + 2 Fo $T^p_{W1N,m}$ + (Q solar + Q sky) / (ρ_{W1N} $Cp_{,W1N}$ A_{W1N} $\frac{\Delta_x}{2\Delta t}$) (4,20)

The Biox number is a dimensionless measurement of the temperature change in the solid relative to the temperature difference between the surface and fluid. The definition of the Bi is given by

$$\text{Bi} = \frac{T^p_{s,1} - T^p_{s,2}}{T^P_{S,2} - T^P_{\infty}} = \frac{R_{cond}}{R_{CONV}} = \frac{(l/kA)}{(L/hA)} = \frac{hL}{k} \qquad (4,21)$$

Where $T_{S,1}$ and $T_{s,2}$ are the temperatures of two surfaces of the solid where the conductive heat transfer occurs, T_{∞} is the temperature of the fluid that invokes the convective heat transfer at the solid-liquid interface, and L is the length of the surface in the direction of the fluid flow. The Biot number in a discretized format is calculated from.

$$\text{Bi} = \frac{h\Delta x}{k} \qquad (4,22)$$

Where Δx is a space increment, in the direction of conduction, which is used to discretize the location of the solid.

The Fourier number (Fo) is a dimensionless time parameter that characterizes transient conduction heat transfer and is defined as

$$Fo = \frac{\alpha - t}{L_C^2} \tag{4.23}$$

Where $\alpha = {}^{k}\!/_{\rho c}$ and the characteristic length (L_C) is the ratio of the solid's volume to surface area, $L_C = {}^{V}\!/_{A}$ = x. The Fourier number (Fo) in a discretized format is calculated from

$$Fo = \frac{\alpha \Delta t}{(\Delta x)^2} = \frac{k \Delta t}{\Delta x^2 \rho c} \tag{4.24}$$

To prevent unstable results, Δt must remain within the stability limit. To satisfy the stability criterion in a case of one-dimensional transient conduction, the value of Δt should be determined as the minimum number that satisfies the following two conditions:

$$Fo \le \frac{1}{2} \quad \text{which means } \Delta t \le \tag{4.25}$$

And for conduction and convection

$$Fo(1 - Bi) \le \frac{1}{2} \quad \text{which means } \Delta t \le \tag{4.26}$$

In the previously listed equation for this node

$$T_{WINi}^{p+1} = T_{WINi}^{p} \left(1\text{-}2\ Fo\,(B_i + 1)\right) + 2\,B_i\ Fo\,T^p_{c1} + 2\,Fo\,T^p_{W1N,\,m} + (Q\ solar + Q\ sky) / \left(\rho_{W1N}\, Cp,_{W1N}\, A_{W1N}\, \frac{\Delta x}{2 \Delta t}\right) \tag{4.20}$$

the value of Bi is the Biot number for the heat transfer between the courtyard air T^p_{c1} and the courtyard wall inside surface node T^p_{W1Ni}. The value of Fo is the Fourier number used at the inside wall surface node T^p_{W1Ni}.

The stability criterion is determined by requiring that the coefficients are greater than or equal to zero. Thus in this case, the value of Δt needs to be determined as the minimum number that satisfies the following two conditions

$$(1-2\ Fo(B_i+1)) \geq 0 \tag{4.27}$$

And

$$Fo(B_i+1) \leq \frac{1}{2} \tag{4.28}$$

4.3.2.3.4 The Interior Wall Node, $T_{W1N,m}$

Next it is necessary to consider the energy balance at the interior wall node $T_{W1N,m}$ (nodes # 5, 2, 13, 10). A time lag exists in the heat transfer from a surface to the opposite surface of the wall. The heat temporarily stored inside the wall interior node $T_{W1N,m}$ can be calculated from the energy difference between the heat transfer toward the left. hand side (i.e., the inside) and that toward the right hand side (i.e., the outside). Thus the heat balance at the wall interior node $T_{W1N,m}$ is

$$Q_{cond}(T_{W1N,i}-T_{W1N,m}) + Q_{cond}(T_{W1N,m}-T_{W1N,o}) = Q_{store} \tag{4.29}$$

The explicit finite difference expression for this heat transfer is

$$\frac{K_{avg}\ A_{W1N}}{\Delta_X}(T^p_{W1N,i}-T^p_{W1N,m}) + \frac{K_{avg}\ A_{W1N}}{\Delta_X}(T^p_{W1N,o}-T^p_{W1N,m}) = \rho_{W1N}\ Cp_{,W1N}\ A_{W1N}\ (\Delta_x)\ ((T^{p+1}_{W1N,m}-T^p_{W1N,m})/\Delta t) \tag{4.30}$$

Solving for $T^{p+1}_{W1N,m}$, the future temperature of the interior wall node m yields

$$T^{p+1}_{W1N,m} = \frac{K_{avg}\ \Delta t}{\rho_{W1N}\, c_{P,W1N}\, \Delta_X^2}(T^p_{W1N,i}-T^p_{W1N,m}) + \frac{K_{avg}\ \Delta t}{\rho_{W1N}\, c_{P,W1N}\, \Delta_X^2}(T^p_{W1N,o}-T^p_{W1N,m}) + (T^p_{W1N,m}) \tag{4.31}$$

Using the Fourier substitution $F_O = \dfrac{K_{avg}\,\Delta t}{\rho_{W1N} c_{P,W1N} \Delta_X^2}$ yields

$$T^{p+1}_{W1N,m} = F_O\, T^{p}_{W1N,i} + F_o T^{p}_{W1N,o} + (1 - 2F_o)\, T^{p}_{W1N,m} \tag{4.32}$$

Where $T^{p+1}_{W1N,m}$ and $T^{p}_{W1N,m}$ are the future and the previous temperatures respectively of the given interior wall node. The values of $T^{p}_{W1N,i}$ and $T^{p}_{W1N,o}$ are the previous temperatures measured at the wall nodes on both side of the current node. The Fourier number is the Fourier number at the given interior wall node m, the stability criterion is determined by requiring that the coefficients are greater than or equal to zero. Thus, the two stability conditions to determine the discrete time Δt are similar to those for the previous node.

4.3.2.3.5 The Wall Outside Surface Node, $T_{W1N,o}$

The energy balance must also be considered at the outside surface wall node, $T_{W1N,o}$ (nodes # *3, 6, 11 and 14***)**. The energy balance at the outside wall surface node is

$$Q_{conv\,(W1N,o)} + Q_{cond\,(T_{W1N,m} - T_{W1N,o})} = Q_{store} \tag{4.33}$$

The explicit finite difference expression is

$$h_{W1N} A_{W1N} (T^{p}_{o} - T^{p}_{W1No}) + (k_{avg} Aw/\Delta_x)(T^{p}_{W1N,m} - T^{p}_{W1N,o}) = \rho_{W1N} Cp_{,W1N} A_{W1N} (\Delta_x/2)((T^{p+1}_{W1N,o} - T^{p}_{W1N,o})/\Delta t) \tag{4.34}$$

Solving for the future temperature $T^{p+1}_{WIN,o}$, yields

$$T^{p+1}_{W1N,o} = \left(1 - \frac{2h_{W1N}\Delta t}{\rho_{W1N} C_{p,W1N} \Delta_X} - \frac{2K_{avg}\Delta t}{\rho_{W1N} C_{P,W1`N} \Delta_x^2}\right) T^{p}_{W1N,o} + \frac{2h_{W1N}\Delta t T_o^p}{\rho_{W1N} C_{P,W1N} \Delta_x} + \frac{2K_{avg}\Delta t T^{p}_{W1N,m}}{\rho_{W1N} C_{P,W1`N} \Delta_x^2} \tag{4.35}$$

Using $B_i = (h_{W1N} \Delta x) / k_{avg}$ and $Fo = \dfrac{K_{avg}\Delta t}{\rho_{W1N} C_{P,W1`N} \Delta_x^2}$, we can simplify it as follows

$$T_{WIN,o}^{p+1} = (1 - 2Fo(B_i + 1))\, T_{W1N,o}^{p} + 2Fo\, T_{W1N,m}^{P} + 2B_i Fo\, T_O^P \qquad (4.36)$$

Where $T_{WIN,o}^{p+1}$ and $T_{W1N,o}^{p}$ are the new and the previous temperatures of the outside wall surface, and T_O^P is the previous ambient temperature. The value of $T_{W1N,m}^{P}$ is the previous temperature at the interior wall node. The value of B_i is the Biot number considering the heat transfer between the outside wall surface temperature $T_{W1N,o}^{p}$ and the ambient air temperature T_O^P where convection is assumed to be the dominant heat transfer mechanism. The value of the Fo, is for the Fourier number at the outside wall surface node $T_{W1N,o}^{p}$. Thus, the two stability conditions to determine the discrete time Δt are similar to those for the previous nodes.

4.3.2.3.6 The Courtyard Ground Node, T_G

Finally, I shall discuss the energy balance at the courtyard ground node T_G *(# 7)*. The energy balance at the courtyard ground node is

$$Q_{conv\,(G,i)} + Q_{solar} + Q_{rad,sky(TG\,i)} + Q_{cond}\,(T_{G,m} - T_{G,i}) = Q_{store} \qquad (4.37)$$

The explicit finite difference expression for this heat transfer is

$$h_G A_G (T^p_{C1} - T^p_{G,i}) + Q_{solar} + Q_{rad,sky(G\,i)} + (k_{avg} A_G / \Delta_x)(T_{G,m} - T_{G,i}) = \rho_G C_{p,G} A_G (\Delta_x/2) \frac{(T_{Gi}^{p+1} - T_{G,i}^{p})}{\Delta t} \qquad (4.38)$$

Solving for $T_{G,i}^{p+1}$, the future temperature of the interior wall node m yields

$$T_{G,i}^{p+1} = T_{G,i}^{p} + (T^{p}_{C1} - T^{p}_{G,i})\ 2\,h_G\,\Delta t / (\rho_G\,Cp_{,G}\,\Delta_x) + (T_{G,m} - T_{G,i})\,(2\,\Delta t\ k_{avg}) /$$

$$(\Delta_x^2\,\rho_G\,C_{p,G}) + (Q_{solar} + Q_{rad,sky(G,i)}) / (\rho_G\,Cp_{,G}\,A_G\,\frac{\Delta_x}{2\Delta t}) \qquad (4.39)$$

Using $B_i = (h_G\,\Delta x) / k_{avg}$ and $Fo = \dfrac{K_{avg}\Delta t}{\rho_G C_{P,G} \Delta_x^2}$ we can simplify it as follows

$$T_{G,i}^{p+1} = T_{G,i}^{p}\ (1 - 2\,Fo\,(B_i + 1)) + 2\,B_i\ Fo\,T^{p}_{C1} + 2\,Fo\,T_{G,m} + (Q_{solar} + Q$$

$$_{rad,sky(G,i)}) / (\rho_G\,Cp_{,G}\,A_G\,\frac{\Delta_x}{2\Delta t}) \qquad (4.40)$$

Where $T_{G,i}^{p+1}$ and $T_{G,i}^{p}$ are the new and the previous temperatures of the courtyard ground surface, and T^{p}_{C1} is the previous courtyard lower node temperature. The value of $T_{G,m}$ is the previous temperature at the interior ground node. The value of B_i is the Biot number considering the heat transfer between the outside wall surface ground $T_{G,i}^{p}$ and the courtyard lower node temperature T^{p}_{C1} where convection is assumed to be the dominant heat transfer mechanism. The value of the Fo, is for the Fourier number at the outside wall surface node T^{p}_{C1}. The equations for the stability criterion are similar to those for the previous nodes.

4.3.2.4 Calculation of the FD Model Using a Spreadsheet

The FD thermal network model for the courtyard microclimate was processed using a Microsoft Excel spreadsheet. The finite difference equations were typed in a row of the spreadsheet to calculate the nodal temperatures at the first new time. These equations in this row are then copied through the whole simulation period. The rows included two consecutive years, where microclimate data were generated for the winter monitoring period starting in December of the first year and ending in January of the second year, and for the summer monitoring period of August from the second year.

This would allow the consideration of the simulation convergence as described in detail in chapter V.

4.3.3 Calibration of the FD and DOE-2 Simulation Models

The measured hourly indoor temperatures for the reception hall in the ground floor during the monitoring periods of twenty one days in August, 2001, and twenty one days in December, 2001 - January, 2002 were used as an indicator of how well the base case DOE-2 simulation model represented the real building. Similarly, the measured hourly courtyard microclimate temperatures at two heights (10ft. and 20ft.) during the 21 days monitoring periods in August, 2001and in December, 2001 - January,2002 were used as an indicator of how well the FD simulation model represented the courtyard microclimate. Once the simulated temperatures matched the measured data in a satisfactory way, the DOE-2 simulation model and the FD microclimate simulation were then declared calibrated.

The flowchart in Figure 4.8 outlines the process through which DOE-2 and the FD microclimate models were combined to simulate the indoor air temperatures of the case study courtyard house for the winter and summer monitoring periods. The calibration process began by first running DOE-2 simulation for the case study courtyard house using the Cairo IWEC weather file including the ambient weather data during the monitoring periods of twenty one days in August, 2001 and twenty one days in December, 2001 - January, 2002. This was considered to be the base case. Second, the FD model was then calibrated to the measured microclimate records during the monitoring periods. Then an annual courtyard microclimate weather file was obtained from the calibrated FD model simulation. Third, courtyard weather file was then used by DOE-2 as the annual hourly weather data for the inner ring of the courtyard house adjacent to the courtyard. Fourth, the IWEC weather file including the rooftop weather data during the monitoring periods was used by DOE-2 for the annual hourly temperature calculations for the outer ring of the courtyard house.

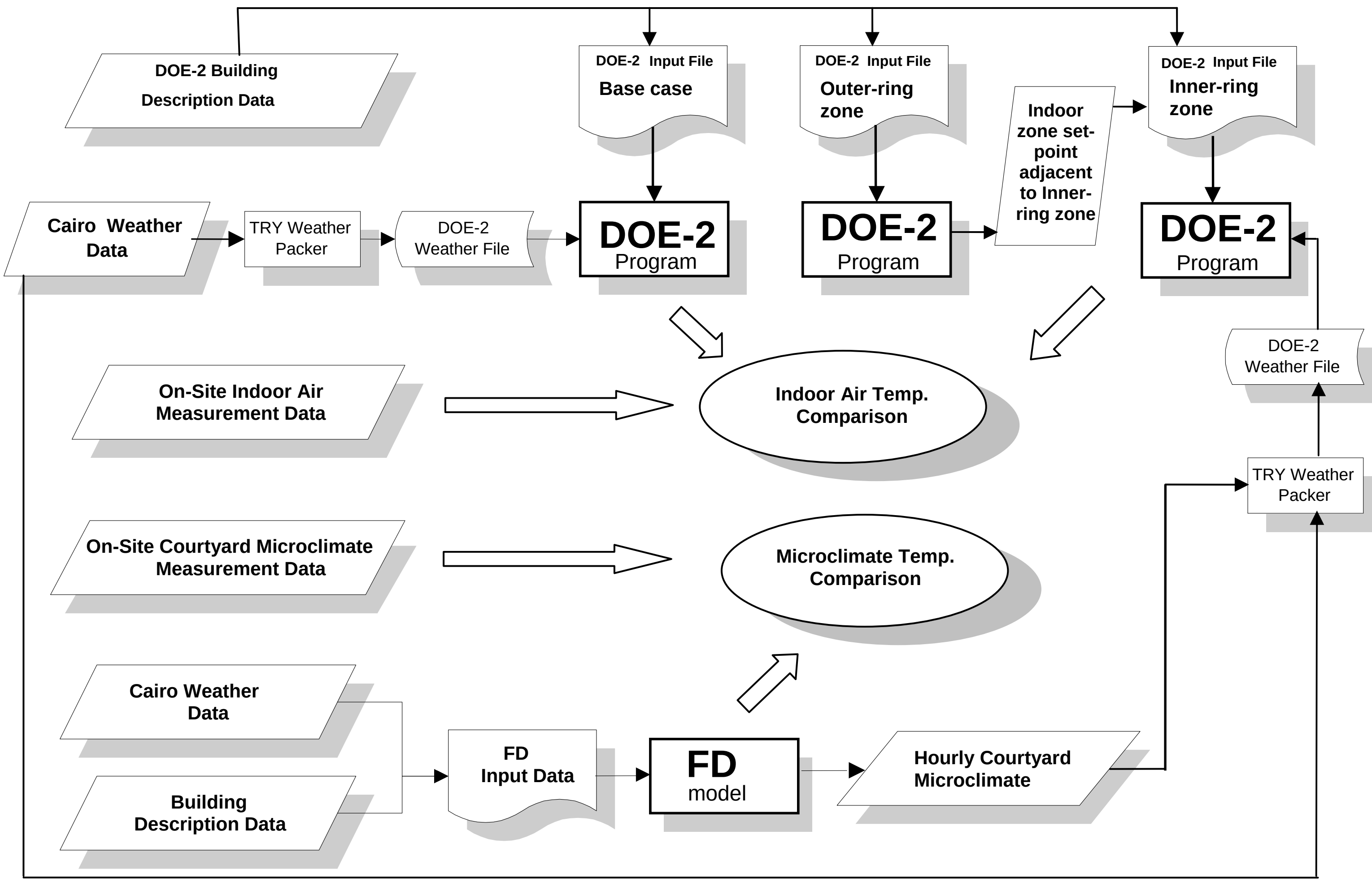


Figure 4.8 Flowchart Diagram Showing the DOE-2 & FD Model Calibration Processes.

In terms of the statistical analyses concerning modeling uncertainty and error, the Coefficient of Variation for the Root Mean Squared Error (CV-RMSE) and the Normalized Mean Biased Error (NMBE) were used as indices for the comparison (Kreider and Haberl. 1994). The following are the equations for the previously mentioned two indices:

- Normalized Mean Bias Error (MBE):

$$\text{NMBE} = \frac{\sum^{n}(y_i - \hat{y}_i)}{(n-p)\times \bar{y}} \times 100 \qquad (4.41)$$

- Coefficient of Variation of the Root Mean Square Error (CV(RMSE)):

$$\text{CV(RMSE)} = 100 \text{ x } (\sum(y_i - \hat{y}_i)^2 /(n-p)]^{1/2} / \bar{y}$$

(4.42)

Where:

$\hat{y}$ = simulation predicted datum
y_i = measured or utility datum
n = number of data points
p = number of parameters in the model (suggests p=1)
$\bar{y}$ = average of the n data points

The smaller of these values are the better the prediction has performed. ASHRAE Guideline 14 (2002) sets uncertainty or tolerance limits for calibrated simulation as follows: "models are declared calibrated if they produce NMBEs within $\pm 10\%$, and CV-RMSEs within $\pm 30\%$ when using hourly data, or 5% - 15% with monthly data". The previous tolerance values were based on the practical experience of the energy modelers who performed calibrated simulations.

4.4 Summary of Methodology

This chapter describes the overall process developed to create a simulation for the courtyard microclimate, as well as a simulation for a courtyard house. The objective was to develop a simulation model that accurately predicts courtyard microclimates, then to apply this model to test a methodology for simulating courtyard houses. To accomplish this, survey, measurements and data collection procedures were designed, along with a detailed analysis for producing an FD model for simulating the courtyard microclimate, and a methodology for simulating a courtyard house in DOE-2 program were produced.

A survey of candidate traditional courtyard houses in Cairo was discussed and a case study house was selected and presented. The available weather stations were presented and the synthesizing of global horizontal radiation into beam and diffuse components were detailed.

The air temperature and humidity of indoor spaces, rooftop, and courtyard space, as well as the courtyard floor and indoor wall temperatures were monitored using micro data-loggers. Ten data loggers were used in the field monitoring along with an air speed sensor.

An FD thermal network model for predicting the courtyard microclimate was created along with detailed description of the nodal energy balance formulas.

A methodology for simulating a courtyard house in DOE-2 thermal simulation software was laid out that utilizes the weather data produced by the FD microclimate model. In this simulation the house was split into two set of zones: inner zones affected by the courtyard microclimate and outer zones affected by the ambient weather. Technical aspects of simulating an unconditioned building in DOE-2 program were discussed.

Measured hourly temperatures in the courtyard space and inside the house spaces were used as an indicator of how well the simulation models represented (calibration) the case study building. Statistical indices applied in evaluating the calibration of the FD thermal network model for predicting the courtyard microclimate as well as the calibration of the DOE-2 model for simulating the courtyard house were detailed.

CHAPTER V

RESULTS

This chapter discusses the results of the investigation, which include the data collection and measurement results of the case study courtyard house, and the DOE-2/FD calibrated simulation results. Analysis of the results, in terms of the thermal performance of the case study courtyard house is also included in this chapter.

5.1 Data Collection and Measurements of the Case Study Buildings

5.1.1 Cairo Weather Data

The outdoor weather data of Cairo during 2001/2002 were obtained from three sources: 1) on-site measurements, 2) a weather file from the Central Laboratory for Agricultural Climatology CLAC, and 3) Cairo Airport. Outdoor dry-bulb temperatures and relative humidity were measured at the site using the calibrated micro data-loggers. Figure 5.1 presents Cairo weather data for one year showing the CLAC and airport data during the monitoring periods versus the Cairo International Weather for Energy Calculations IWEC (ASHRAE, 2001) file for hourly data of dry-bulb temperature, relative humidity, global horizontal solar radiation, wind speed, average cloud cover, and monthly ground temperature. These data were used to create the DOE-2 weather file. Figures 5.2a and 5.2b present a close-up of the Cairo CLAC and airport weather data for the summer and winter monitoring periods.

5.1.2 Measurement Results of the Case Study Building

Onsite measurements included dry-bulb and relative humidity measurements from the rooftop of the courtyard house, the courtyard air at two heights (10ft., 20ft.), and the ground floor reception hall temperature, in addition to the temperature at the courtyard floor. All were measured using micro data-loggers.

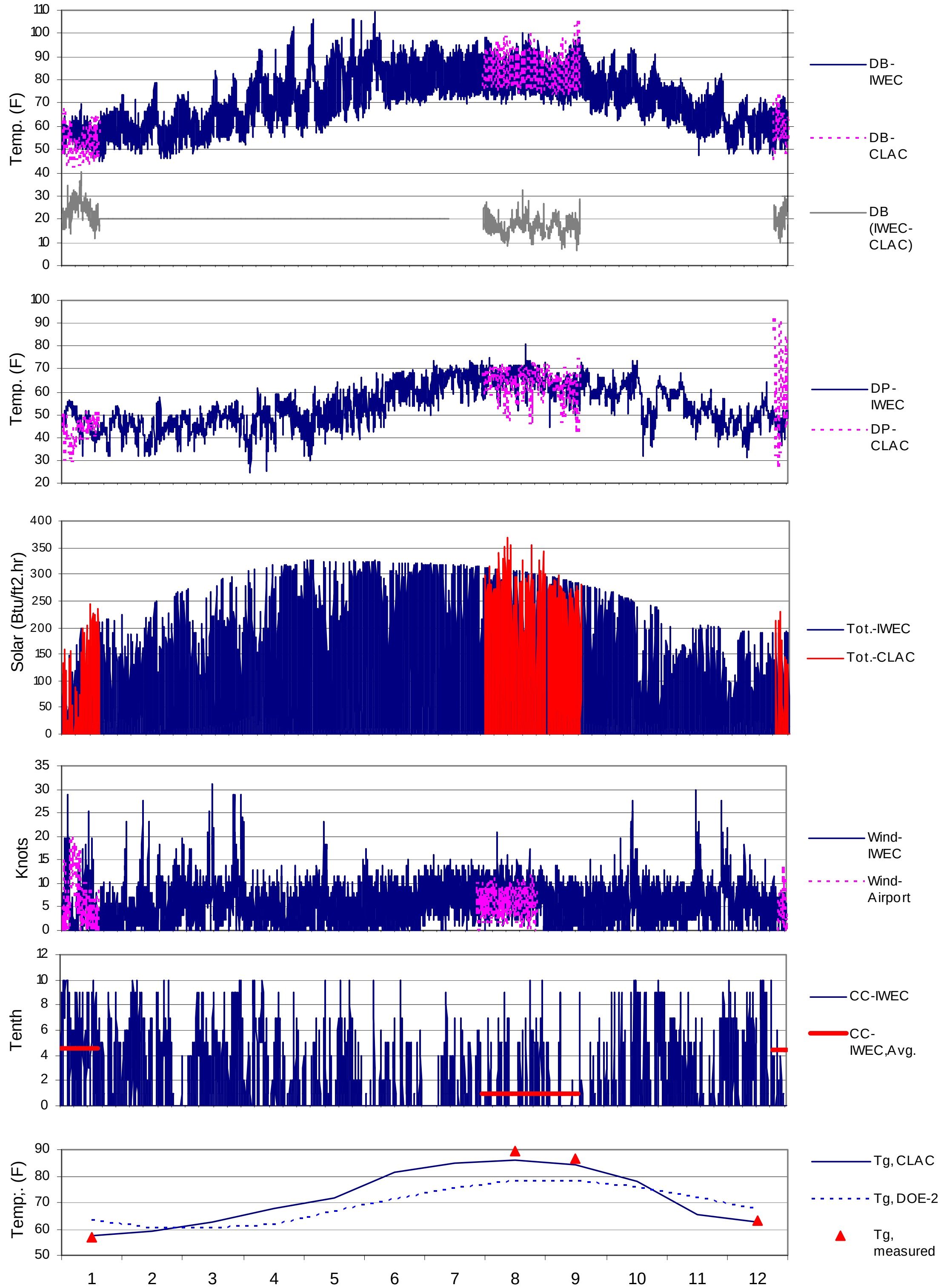


Figure 5.1 Cairo Weather Data for One Year Showing the CLAC and Airport Data During the Monitoring Periods, and the IWEC Data for the Entire Year.

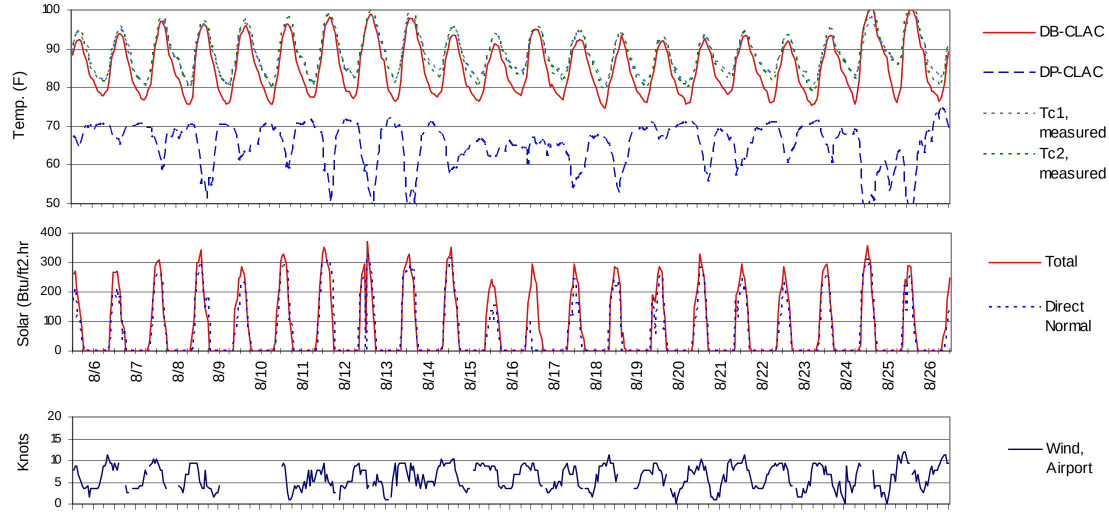


Figure 5.2a Weather Data and Courtyard Microclimate at 10ft. (Tc1) and 20 ft.(Tc2) Monitoring Points During the Summer (August, 2001) Monitoring Period. (Missing wind data were completed in the DOE2 packed weather file by copying data of the previous day).

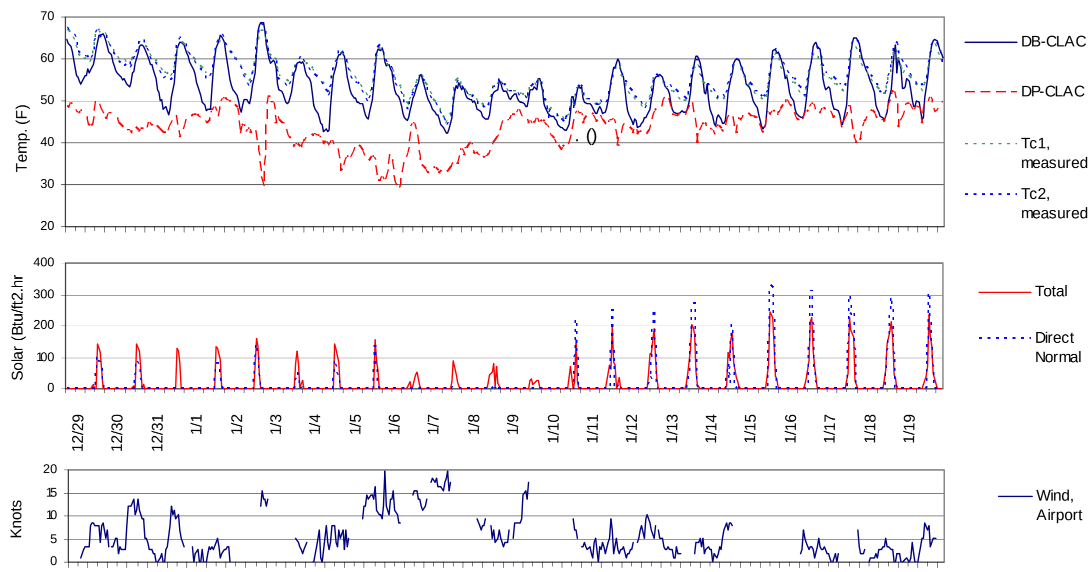


Figure 5.2b Weather Data and Courtyard Microclimate at 10ft. (Tc1) and 20 ft.(Tc2) Monitoring Points During the Winter (December, 2001 - January,2002) Monitoring Period. (Missing wind data were filled-in the DOE2 packed weather file by copying data from the previous day).

Figures 5.3a and 5.3b show the measurements of the case study courtyard house (Rooftop, Courtyard Air (10ft.&20ft.), Indoor Space (Reception Hall), Courtyard Floor**)** in addition to the CLAC weather station dry-bulb temperatures and solar radiation during the winter (December, 2001 - January, 2002) and summer (August, 2001) monitoring periods. The following observations can be made about these Figures:

- The morning temperature spike for the courtyard floor that appeared during the first few days of the summer monitoring period (Figure 5.3b) was due to having the sensor being exposed to direct solar radiation.
- The convergence of temperatures during the period from January 8^{th} to 11^{th} was due to decreased solar radiation.
- The CLAC Tdb is 5-7 ^{o}F lower most nights than the roof Tdb during the winter monitoring period (Figure 5.4a), which supports the significance of onsite measurements.
- The courtyard floor temperature showed the least daily variation during the winter monitoring period, which was expected due to both the absence of solar radiation and the ground thermal mass effect.
- The courtyard floor temperature lags the rooftop temperature at the minimum and maximum daily peaks during both the summer and the winter monitoring periods.
- During the winter monitoring period from December 29^{th} to January 7^{th}, the daily temperature range in the reception room was about 3-7 ^{o}F, in the CLAC it was 10-15 ^{o}F, in the courtyard it was 5-12 ^{o}F, and in the courtyard the floor temperature range was 3-5 ^{o}F.
- During the summer monitoring from August 5^{th} to 26^{th}, the daily temperature range in the reception room was about 5-7 ^{o}F, in the CLAC it was 10-15 ^{o}F, in the courtyard it was 10-18 ^{o}F, and in the courtyard the floor temperature range was 5-12 ^{o}F.

Figures 5.4 a, b & c compare the temperature differences between the rooftop, courtyard microclimate (i.e., the average of the 10 ft. &20 ft. measurements), and the

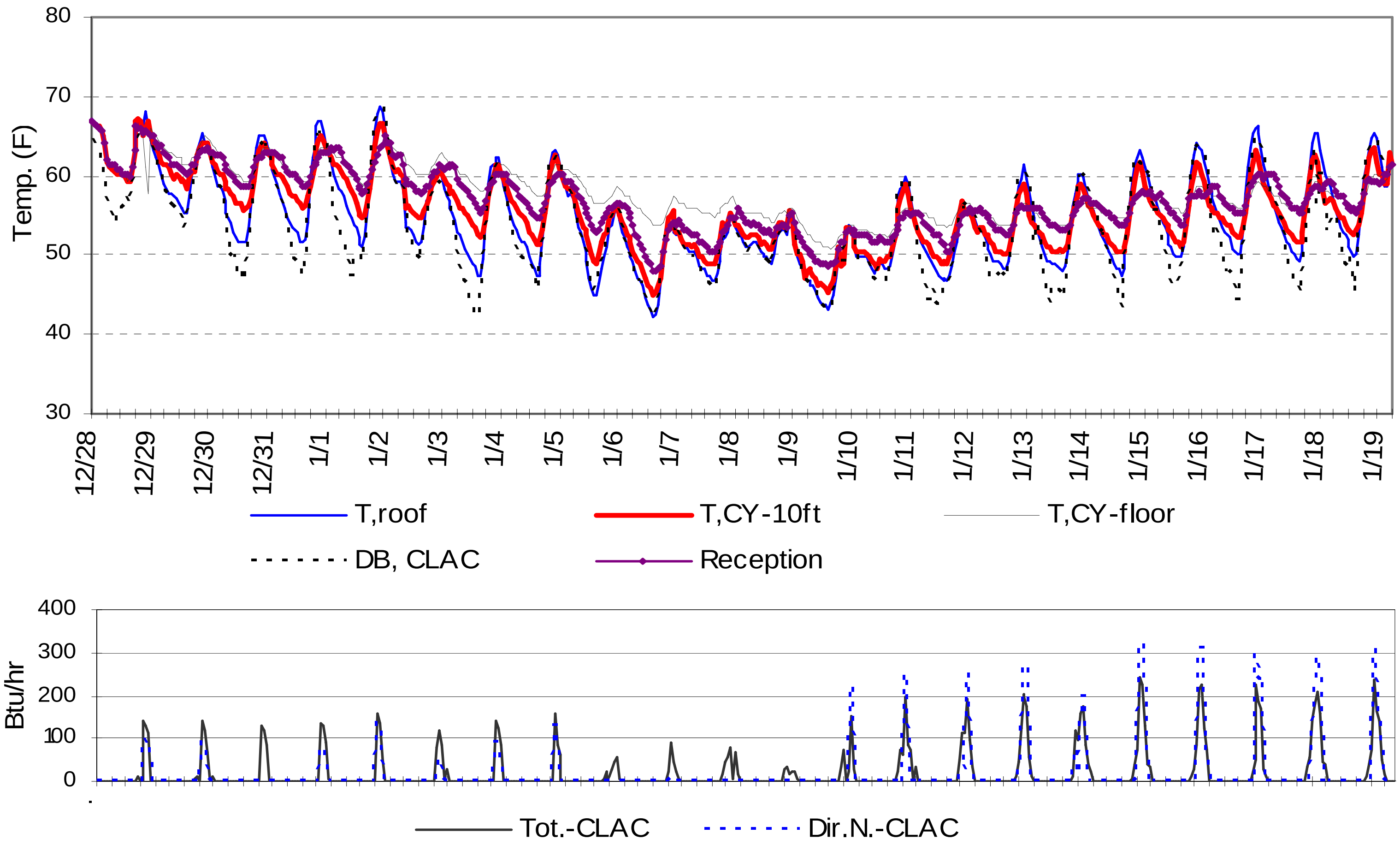


Figure 5.3a Rooftop, Courtyard Air (10ft.&20ft.), Indoor Space (Reception Hall), Courtyard Floor, and CLAC Weather Station Dry-bulb Temperatures (December 29, 2001 - January 19, 2002 Monitoring Period).

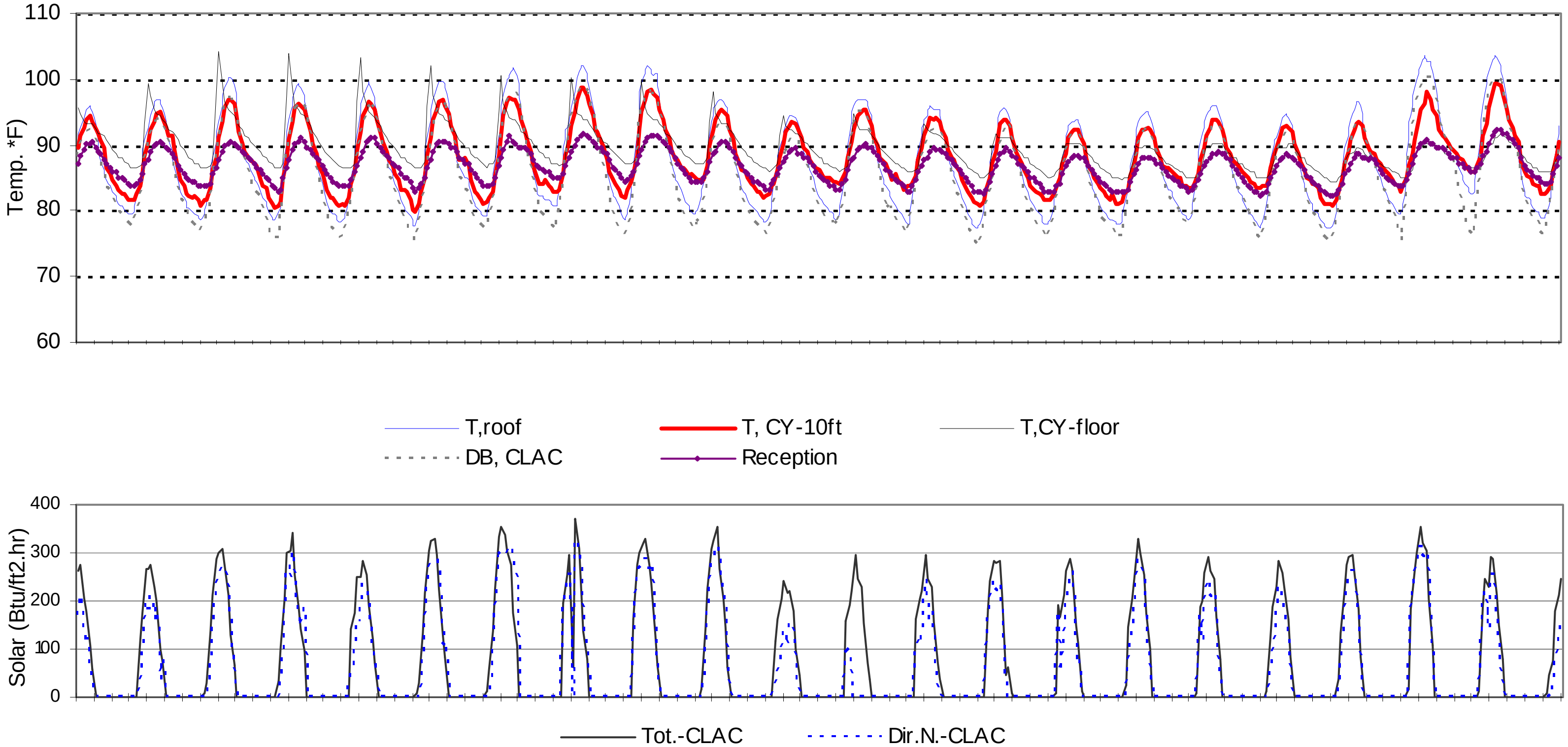


Figure 5.3b Rooftop, Courtyard Air (10ft.&20ft.), Indoor Space (Reception Hall), Courtyard Floor , and CLAC Weather Station Dry-bulb Temperatures During the Summer (August 6-26, 2001 Monitoring Period).

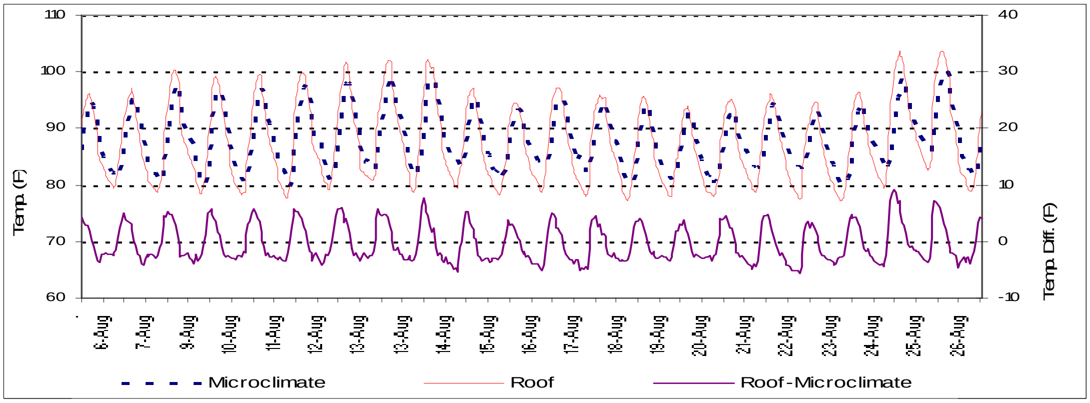


Figure 5.4a Rooftop and Courtyard Microclimate (Avg. 10&20 ft.), and the Temperature Difference (August 6-26, 2001 Monitoring Period).

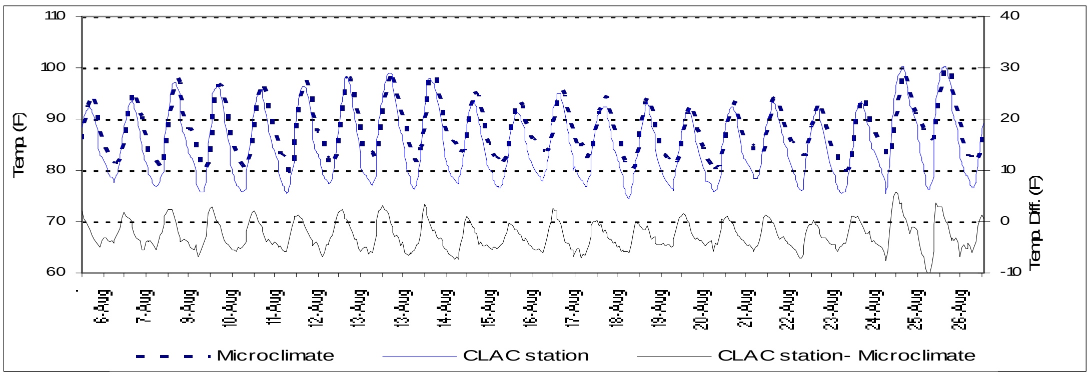


Figure 5.4b CLAC Weather Station and Courtyard Microclimate (Avg. 10&20 ft.), and the Temperature Difference (August 6-26, 2001 Monitoring Period).

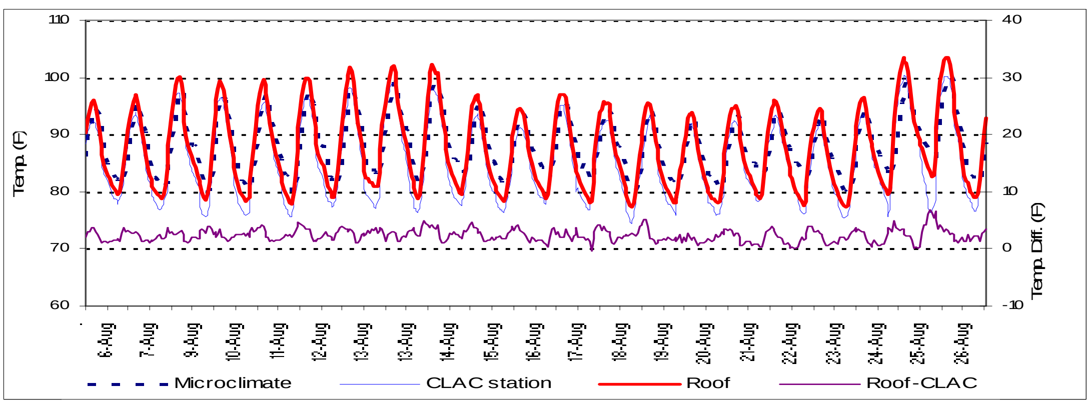


Figure 5.4c Rooftop, CLAC Weather Station, Courtyard Microclimate (Avg. 10&20 ft.), and the Temperature Difference between the Rooftop and the CLAC Weather Station Records (August 6-26, 2001 Monitoring Period).

CLAC weather station during the summer (August, 2001) monitoring period. These plots show:

- Figure 5.4a, which compares the courtyard microclimate and the rooftop temperatures during the summer monitoring period, shows that the courtyard microclimate was cooler from the early morning hours until the late afternoon with a maximum temperature difference reaching a 5-7 ^{o}F. This trend is reversed during the night with a maximum difference reaching 3-5 ^{o}F. Also, during the period from August 9th to 14th, which was characterized by high solar radiation, the courtyard microclimate ranged from 80 to 99 ^{o}F while the rooftop temperature ranged from 79 to 103 ^{o}F.
- Figure 5.4b, which compares the courtyard microclimate and the CLAC weather station temperatures during the summer monitoring period, shows that the courtyard microclimate was cooler for about 3 hours before noon with a maximum temperature difference reaching 2 ^{o}F and is warmer the rest of the day with maximum temperature difference reaching 8 ^{o}F. Also, during the period from August 9th to 14th, which was characterized by high solar radiation, the courtyard microclimate ranged from 80 to 99 ^{o}F, while the CLAC weather station temperature ranged from 77 to 99 ^{o}F.
- The previous two comments regarding Figures 5.4 a & b suggests that the use of rooftop temperatures versus the CLAC weather station temperatures to evaluate or predict the courtyard microclimate would produce completely different results. This difference may be seen in Figure 5.4c that shows the rooftop temperature records being consistently warmer than the CLAC weather station temperatures. In other words, a more accurate model that accounts for the local site microclimate needs to be applied rather than the CLAC weather station records for generating precise simulations and/or evaluations of a building's thermal performance. In this regard it is worth pointing to the specifications for what was named an 'Urban weather station' as opposed to airport weather stations that were established and applied by Bagneid (1987).

Figures 5.5 a, b & c compare the temperature differences between the rooftop, courtyard microclimate (i.e., the average of the 10ft. & 20ft. high points), and the CLAC weather station during the winter (December, 2001 - January, 2002) monitoring period. These plots show:

- In Figure 5.5a, which compares the courtyard microclimate and the rooftop temperatures during the winter monitoring period show that the courtyard microclimate was cooler before noon (for about 4 hours) with a maximum temperature difference reaching 5 ^{o}F, while it was warmer the rest of the day with maximum difference reaching 5 ^{o}F.
- In Figure 5.5b, which compares the courtyard microclimate and the CLAC weather station temperatures during the winter monitoring period show that the courtyard microclimate was cooler prior to noon for less hours with less magnitude than that in graph 5.5a. and was warmer the rest of the day with a maximum temperature difference reaching 10 ^{o}F.
- The previous two comments regarding Figures 5.5a and 5.5b suggests that the use of rooftop temperatures versus the CLAC weather station temperatures in evaluating or predicting the courtyard microclimate during the winter would produce completely different results. This difference may be seen in Figure 5.5c, which shows that the rooftop temperature records being warmer than the CLAC weather station temperatures mostly at night, with the exception of the period form January 7th-11th when there was very little solar radiation.

These finding would suggest that using the CLAC weather station records as the weather file for the courtyard house simulation would impose cooler ambient thermal conditions at night. This would downplay the role of the courtyard recorded microclimate in cooling the building. Thus it is suggested to use a rooftop weather temperature for the DOE-2 simulation instead of the CLAC weather station temperatures.

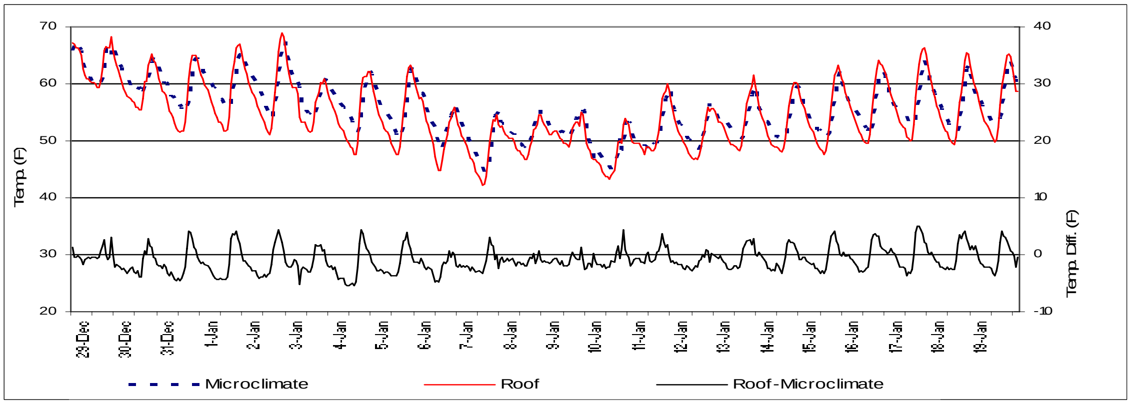


Figure 5.5a Rooftop and Courtyard Microclimate (Avg. 10&20 ft.), and the Temperature Difference (December 29, 2001 - January 19, 2002 Monitoring Period).

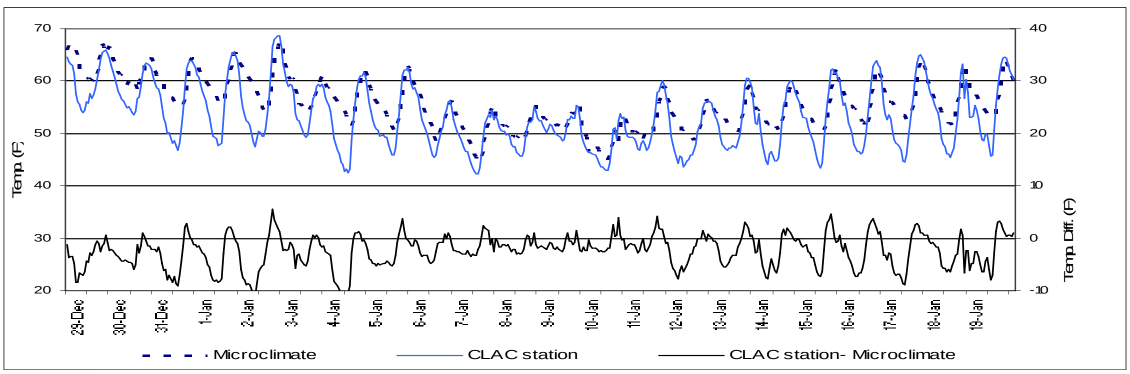


Figure 5.5b CLAC Weather Station and Courtyard Microclimate (Avg. 10&20 ft.), and the Temperature Difference (December 29, 2001 - January 19, 2002 Monitoring Period).

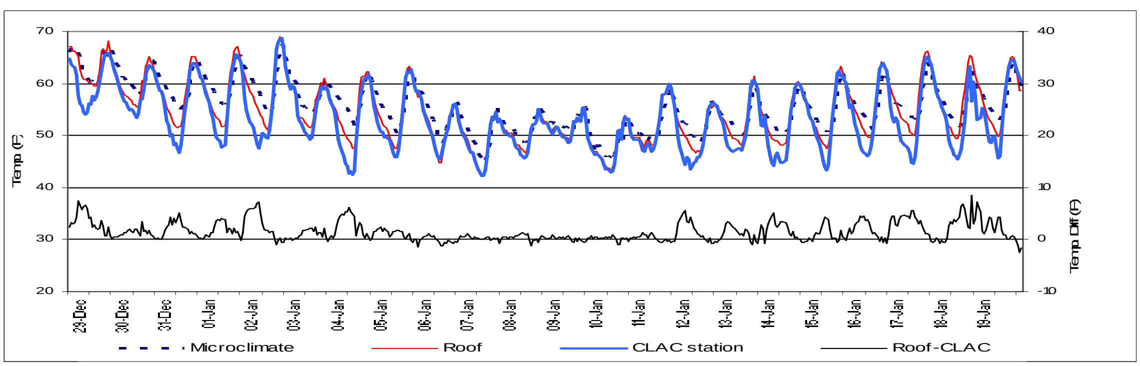


Figure 5.5c Rooftop, CLAC Weather Station, Courtyard Microclimate (Avg. 10&20 ft.), and the Temperature Difference Between the Rooftop and the CLAC Weather Station (December 29, 2001 - January 19, 2002 Monitoring Period).

5.2 Convergence of the Courtyard Microclimate FD Thermal Network Model

The courtyard microclimate FD thermal network model was tested using under convergence tests to determine the time it takes for reaching a steady state condition. The process was conducted through two steps: selecting an iterative day then running the FD model until convergence was reached.

a) The local weather station (CLAC) data was scanned for the hottest and coldest days of the monitoring year. The hottest and coldest days DB, DP, and solar radiation data are presented in Figures 5.6a and 5.6b respectively. The hottest day data were obtained from the rooftop records and were a minimum of 79.5 ^{o}F and a maximum of 97 ^{o}F. The coldest temperatures were obtained from the rooftop records with a minimum of 42.3 ^{o}F and a maximum of 54.6 ^{o}F. Twenty-four hour temperature profiles, based on the minimum and maximum daily temperatures, were synthesized using a sine curve formula to be applied as the iterative days for the convergence runs. Figures 5.7a and 5.8a show the synthesized temperature profiles for the iterative hottest and coldest days.

b) Two convergence runs were made on the courtyard microclimate FD thermal network model for a period of two consecutive years (17,520 hours). Both runs were with an iterative single-day temperature profile. The first run was with the hottest day climatic conditions and the second run was with the coldest day climatic conditions. The convergence tolerance observed was below 0.1 % (~.07%). Dry-bulb temperature, average dew-point temperature, solar radiation, average cloud cover, and average ground temperature were applied for the hottest day and coldest days, each in a separate run. The NMBE and CV(RMSE) were calculated on hourly basis for selected nodes to monitor the state of convergence along time. Figures 5.7b an and 5.8b present the hottest day and coldest day NMBE and CV(RMSE) for the selected nodes, with a line indicating a convergence value of .07%. Four of the selected nodes are within the courtyard FD model walls (# 2,5,10 & 13); which carries the maximum thermal mass (reaching a thickness > 12 ft.) and are expected to need the longest time to reach convergence; along with one node on the surface of the courtyard wall (# 4). The ground node was considered to have a one foot thick of ground mass (Winkelmann, 1998) besides the paving, much less in thickness than the walls, and thus would require less convergence time. The model showed convergence well below the criterion of 0.1 % before reaching the December, 29 of the first year, the first day when the generated courtyard microclimate data were needed.

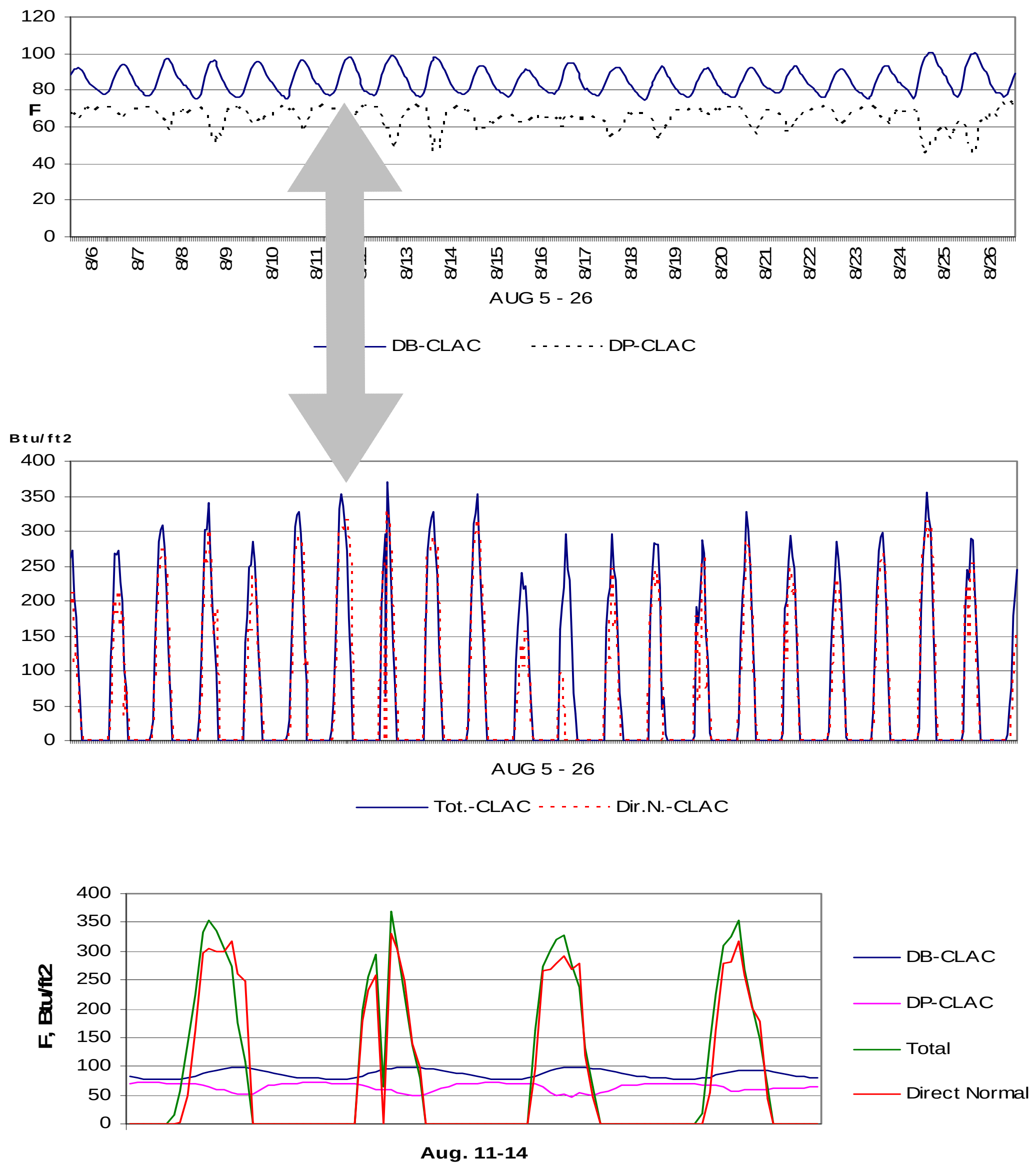


Figure 5.6a Hottest Days Climatic Conditions.

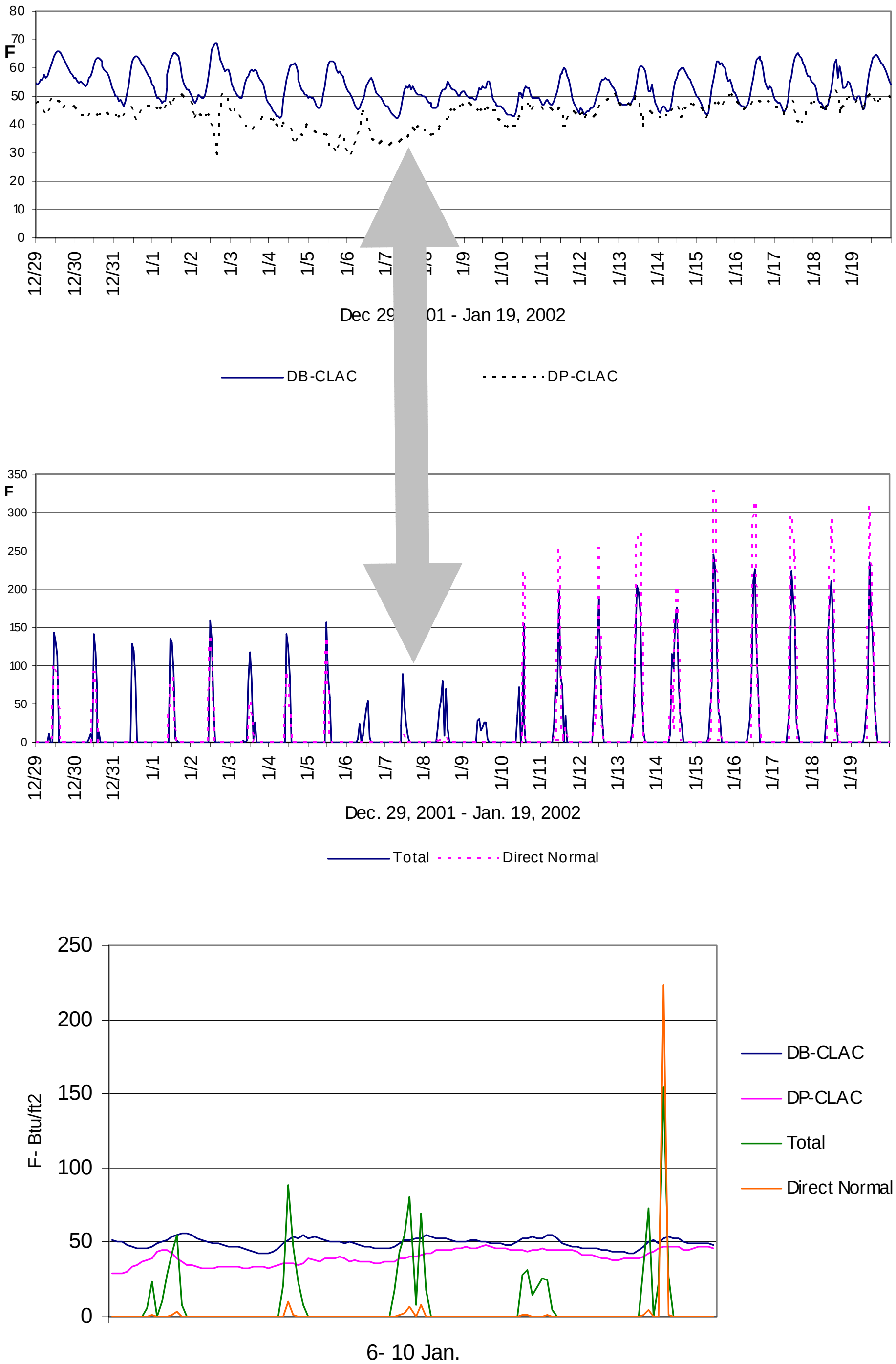


Figure 5.6b Coldest Days Climatic Conditions

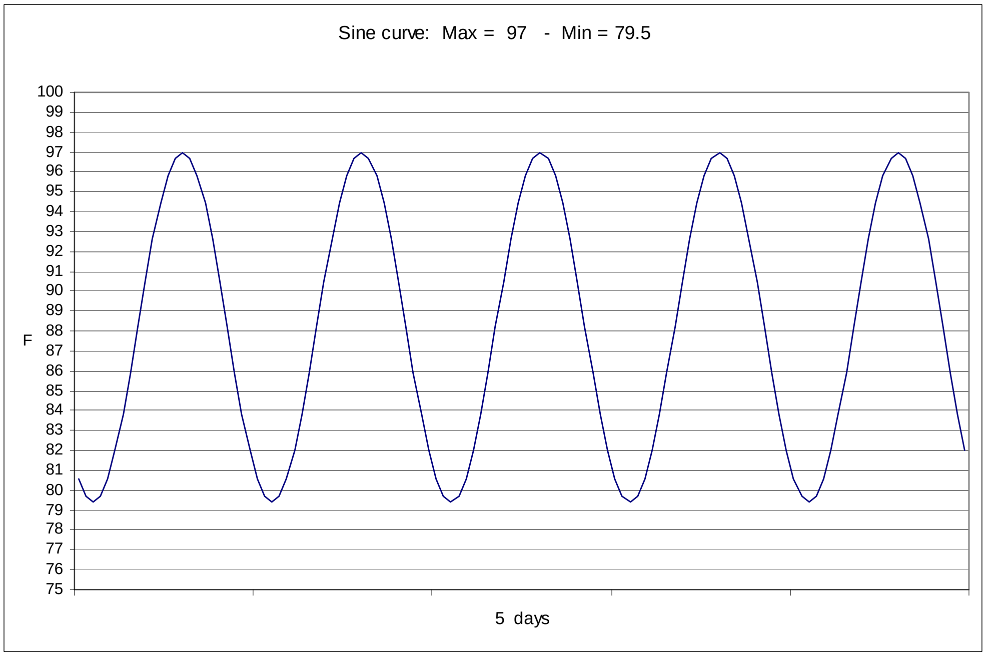


Figure 5.7a Sine Curve Synthesized Daily Temperature Profile for the Hottest Day.

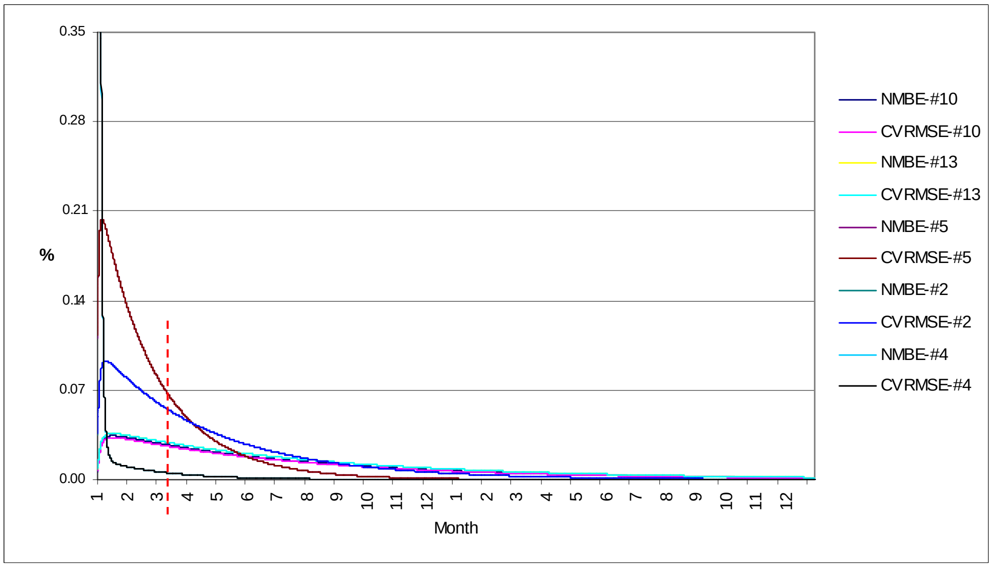


Figure 5.7b NMBE and CV(RMSE) for the Selected Nodes Over a 2 Year Run.

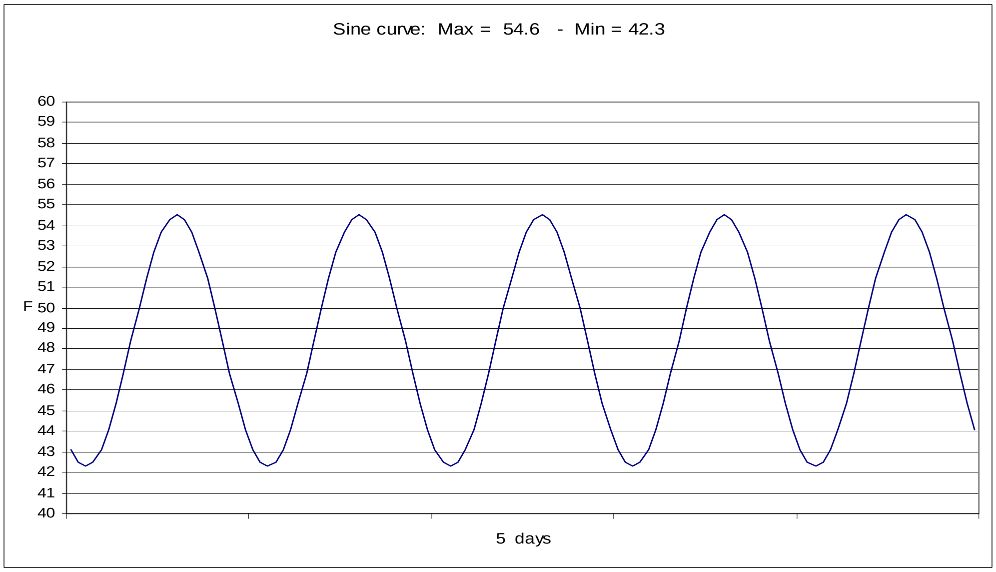


Figure 5.8a Sine Curve Synthesized Daily Temperature Profile for the Coldest Day.

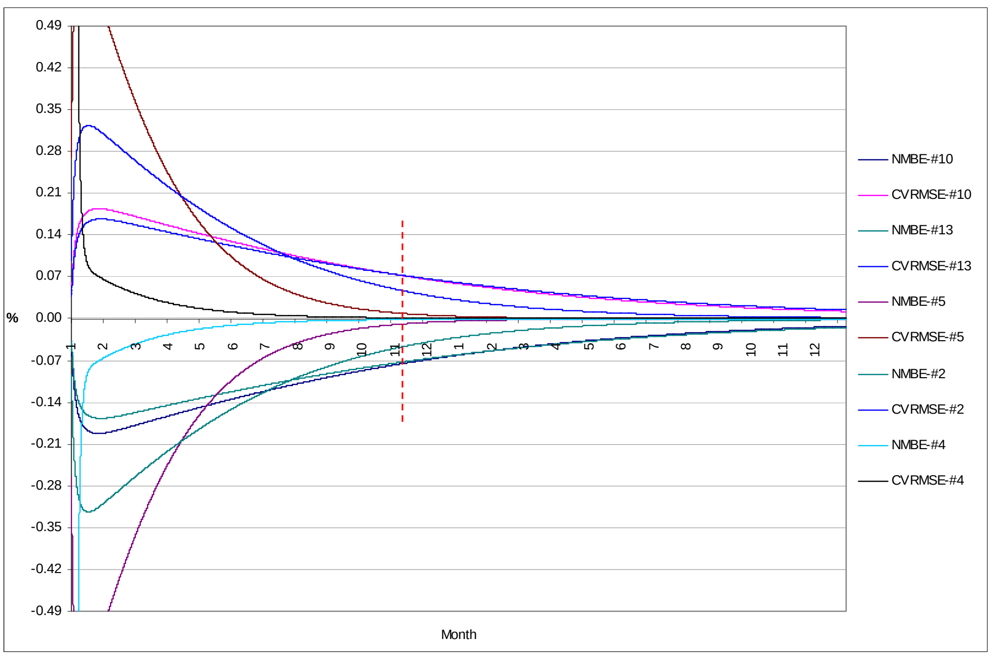


Figure 5.8b NMBE and CV(RMSE) for the Selected Nodes over a 2 Year Run.

5.3 Calibrated Courtyard FD Thermal Network Simulation Results

Annual simulations were made using the courtyard FD thermal network model. In these simulations solar radiation falling on the shaded walls and floor were calculated using the DOE-2 simulation. Table 2.3 showed the convection coefficients used for the exterior walls, courtyard walls and courtyard floor in the FD simulation. Table 2.1 summarizes the previously published measurements of ACH rates inside courtyards. It was decided to test a range of 6 ACH rates for the FD calibration runs (5, 20, 40, 60, 120, & 180 ACH). In the simulation, a daily schedule was applied to the courtyard ACH for the lower courtyard node since the entry gate to the house closes during the night and blocks the airflow. Two rates were applied as the ACH rates between the courtyard nodes and ambient air: the first, which is named 'Type I" has the ACH between the upper node and ambient air equal to a 70% ACH with the ACH between the courtyard lower node and ambient air equal to a 30% ACH, and the second, which is named "Type II" having the ACH between the upper node and ambient air equal to a 90% ACH with the ACH between the courtyard lower node and ambient air equal to a 10% ACH. In both types the ACH between the upper and lower nodes is 50% in both directions. For runs applying ACH factors, 6 basic values were used for the courtyard ACH (5, 20, 40, 60, 120, & 180) and 2 types (I&II) were used for the ACH between nodes, resulting in 12 runs total. Table 5.1 summarizes the values of variables applied to the FD model. It is worth noting that a wind-tunnel model for the case study house with the surrounding buildings and landscape was built and preliminary tests were made in the wind-tunnel laboratory at the Department of Aerospace Engineering at Texas A&M University. Yet due to limited resources (equipment and time), the experiments did not take place. Nevertheless, section 5.4.1 investigated the sensitivity of the courtyard FD thermal model for a wide range of ACH rates.

Two sets of calibrations were applied to the courtyard microclimate FD model:

a) the first analyzes the amount of the thermal mass surrounding the courtyard and,

b) the second analyzes the ACH rates.

Table 5.1 FD Model Input Variables.

	Variable	Value		comments	Source
	Case-study House				
	Absorptivity	Walls = 0.65	Floor = 0.85	As is	ASHRAE
	Emmisivity	Walls = 0.85	Floor = 0.70	As is	ASHRAE
	Conductivity	Walls = 1.04	Floor =1.04	Weighted	ASHRAE
	Specific heat	Walls = 0.217	Floor = 0.217	Weighted	ASHRAE
	Density	Walls = 140	Floor = 103	Weighted	ASHRAE
	Convection coefficient	Windward wall = 1.526, Leeward wall = 1.33	Floor = 1.09	See Table 2.2	ASHRAE - Al-Jared (1991)
	Areas of walls and floor			Main courtyard of the case-study house	Drawings
	Sky view factors	Walls: 0.265-0.265-0.237-0.237	Floor: 0.127	Main courtyard of the case-study house	Calculated
	Mass			Main courtyard and the case-study house	Drawings
	Ambiant weather				
	Dry-bulb temperature				Rooftop & IWEC
	Relative-humidity				
	Ground temperature			Average monthly	CLAC
	Cloud cover (for long wave radaition)			Average value for the monitoring periods	IWEC
	Solar radiation			Solar radiation (Btu/ft2) on walls and floors were calculated by the DOE-2 abstract house model simulation.	CLAC & IWEC
	Wind speed				Airport & IWEC
	Airflow rate			Tests applied 6 types of ACH rates, and 2 types of airflow % per node making a tota**l of 2x6= 12** tests	
A	**Courtyard ACH (three rates)**				
	Total courtyard ACH with ambient air	5,20,40,60,120&180		See Table 2.1	Literature
		Day	Night		
B	**Airflow ACH % per node (TYPE I) :**	8 am -10 pm	10 pm -8 am	Two types of airflow % per node were tested	Assumed
1	Between courtyard lower node and ambient air	30%	0%		
2	Between courtyard upper node and ambient air	70%	70%		
	Internal ACH within the courtyard nodes:				
3	Between courtyard lower node and upper node.	50%	50%		
4	Between courtyard upper node and lower node.	50%	50%		
B	**Airflow ACH % per node (TYPE II) :**	8 am -10 pm	10 pm -8 am		
1	Between courtyard lower node and ambient air	10%	0%		
2	Between courtyard upper node and ambient air	90%	90%		
	Internal ACH within the courtyard nodes:				
3	Between courtyard lower node and upper node.	50%	50%		
4	Between courtyard upper node and lower node.	50%	50%		
C	**Wind speed factor (four hourly patterns)**			See Graph 5.12	Generated
1	ACH x (hourly wind speed / daily avg. wind speed)				
2	ACH x (hourly wind speed / monthly avg. wind speed)				
3	ACH x (daily avg. wind speed / annual max daily avg. wind speed)				
4	ACH x (weekly avg. wind speed / annual max weekly avg. wind speed)				

The NMBE and CV(RMSE) statistical indices were used to score the test runs in order to choose the best fit.

5.3.1 First Calibration: Thermal Mass

Simulations were made on the courtyard microclimate FD model while varying the thermal mass of the walls surrounding it from 0.5 of the courtyard wall thickness up to the whole house thermal mass. In all runs the courtyard ACH was set to 35 and the airflow percentages between the nodes set to 'Type II'. The following six variations were then applied to the thickness of the wall surrounding the courtyard:

1. 0.5 Courtyard envelope.
2. Courtyard envelope.
3. Courtyard envelope + 25% of the house internal mass.
4. Courtyard envelope + 50% of the house internal mass.
5. Courtyard envelope + 75% of the house internal mass.
6. Total house mass.

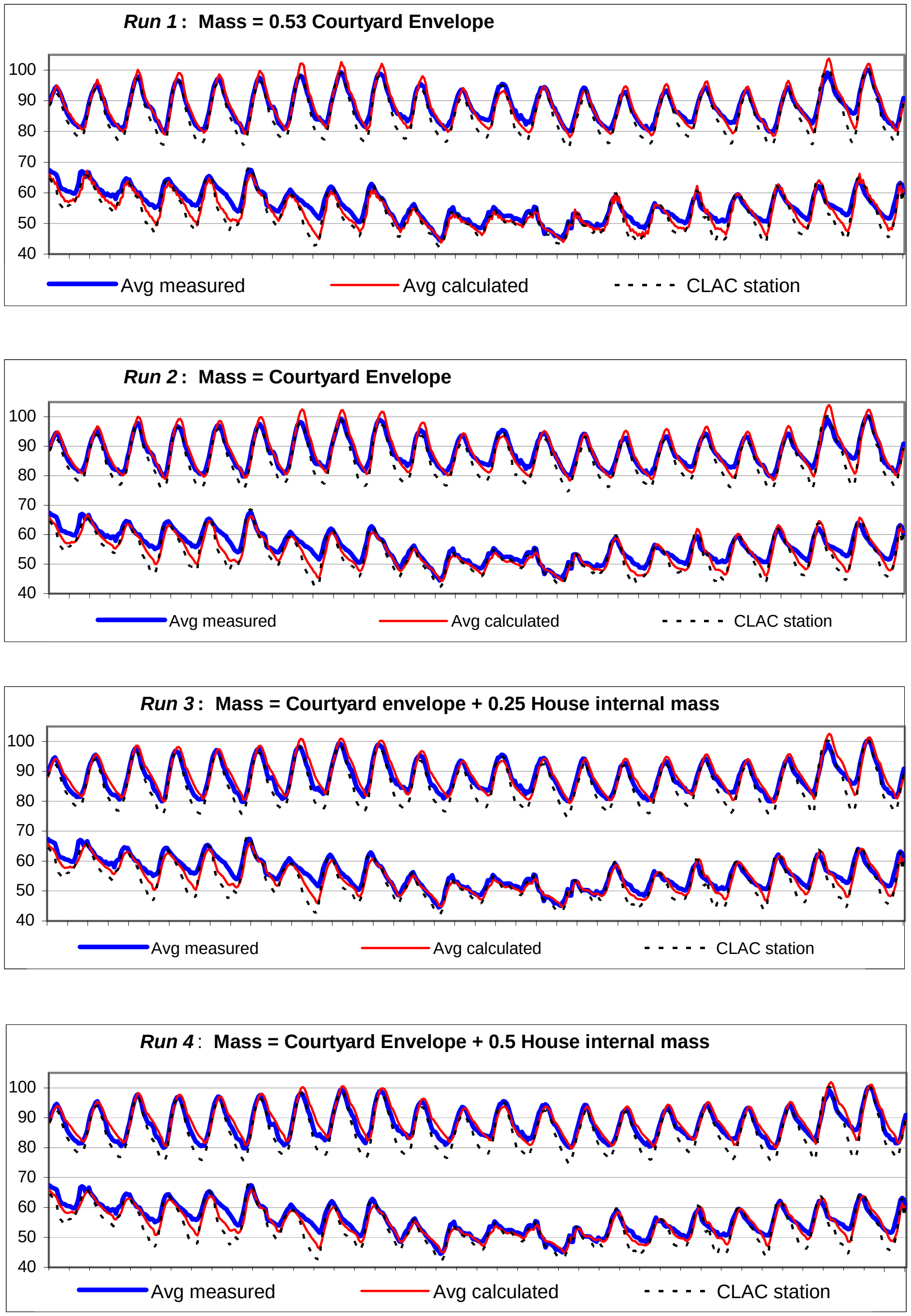
Figure 5.9 shows that the 'total house mass' gave the best CV(RMSE) & NMBE calibration results:

	CV(RMSE)	NMBE
August:	1.0	2.1
January:	-1.5	3.2

The change in the resulting CV(RMSE) & NMBE between the applied runs was small, yet the best fit was obtained with the application of the total house mass. This points to a new finding that a courtyard house thermal mass not only affects the thermal performance of the internal spaces but also affects the courtyard thermal performance.

5.3.2 Second Calibration: Courtyard ACH Rates

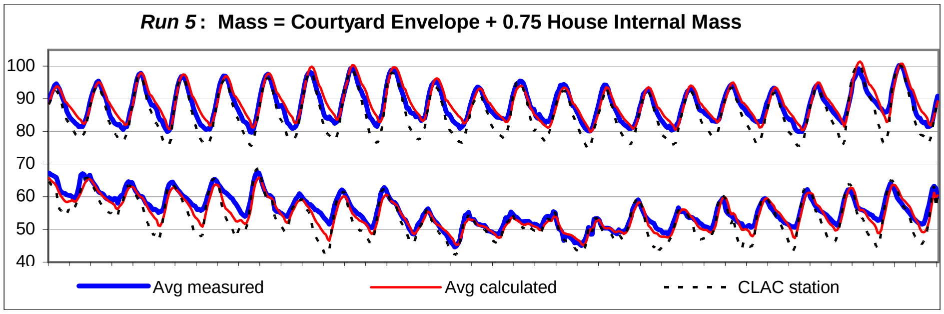
Runs were then made while varying the courtyard ACH rates between 5, 20, 40, 60, 120, and 180. The airflow percentages between the nodes considered both type I & II simulations, making a total of 12 runs = (6 ACH rates times 2 airflow percentages). In all runs the total house mass plus all of the internal mass that gave the best results from the first calibration was applied.



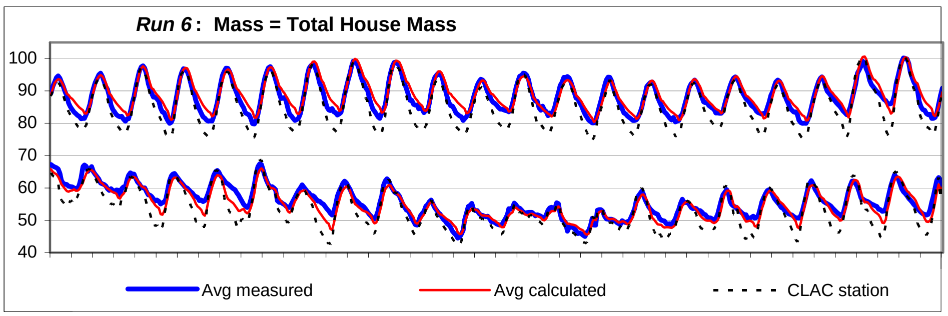
	CVRMSE	NMBE
AUG	-0.1	2.0
JAN	-3.2	4.8
AUG	0.2	2.2
JAN	-3.1	4.7
AUG	0.8	2.4
JAN	-2.5	4.1
AUG	0.9	2.3
JAN	-2.2	3.8

ACH = 35 ACH   Airflow % per node = Type II

Figure 5.9 First Calibration Runs for the Courtyard Microclimate FD Model of 6 Thermal Mass Variations

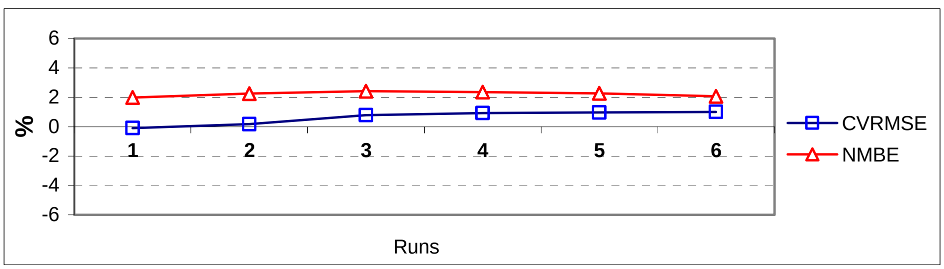


	CVRMSE	NMBE
AUG	1.0	2.3
JAN	-1.9	3.6

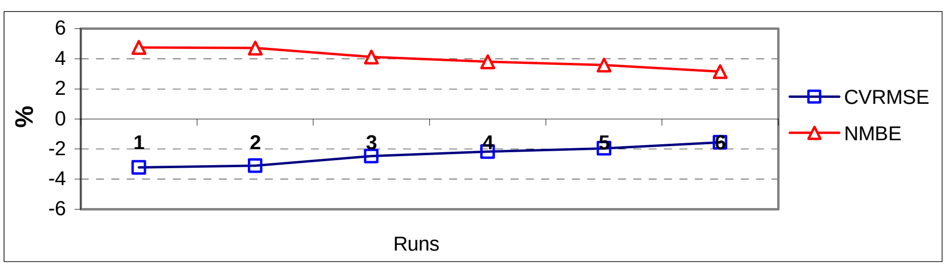


AUG	1.0	2.1
JAN	-1.5	3.2

ACH = 35 ACH   Airflow % per node = Type II



Summer



Winter

Run 1   0.5 courtyard envelope
Run 2   Courtyard envelope.
Run 3   Courtyard envelope + 0.25 house internal mass
Run 4   Courtyard envelope + 0.5 House internal mass.
Run 5   Courtyard envelope + 0.75% house Internal mass
Run 6   Total house mass

Figure 5.9 (continued)

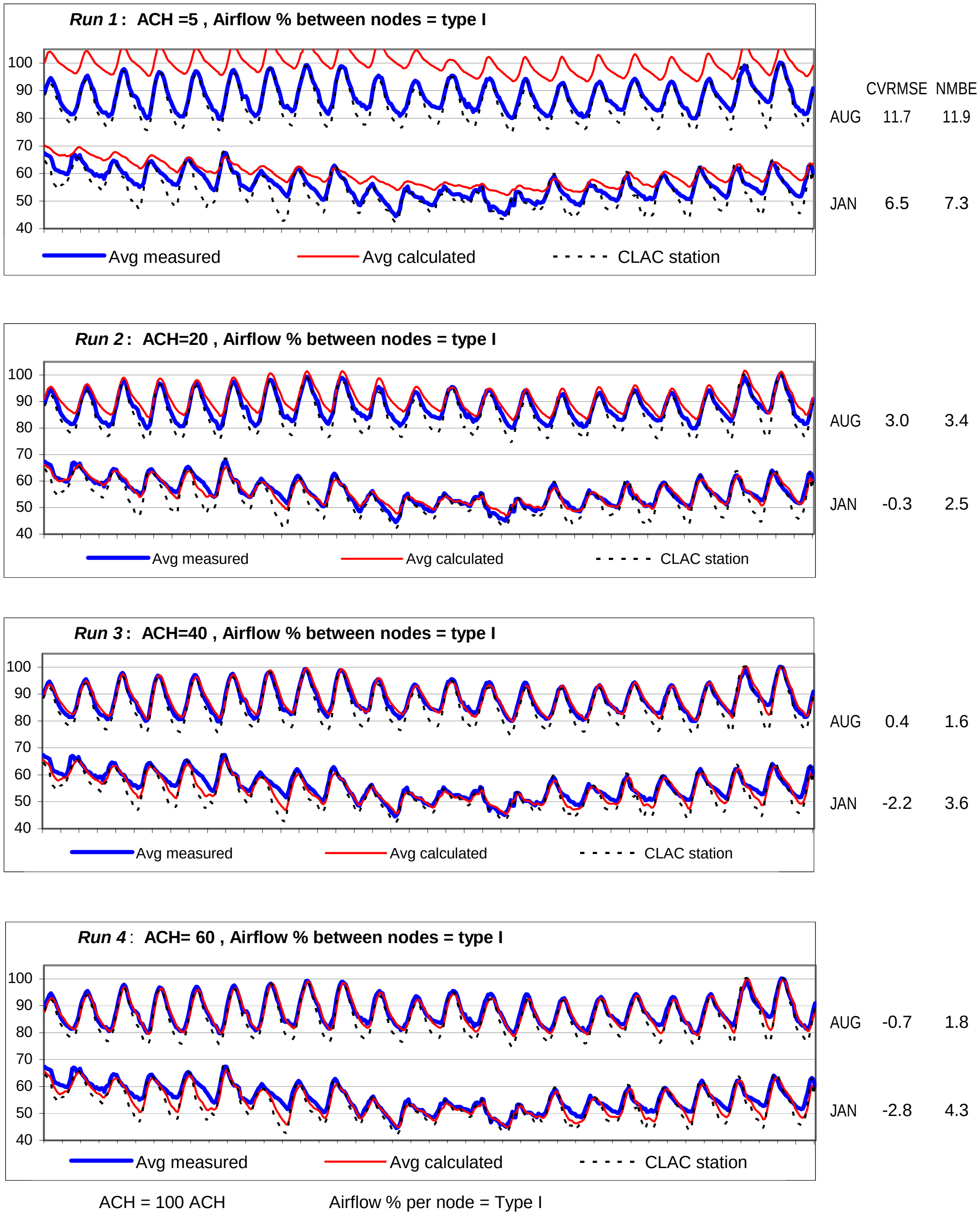
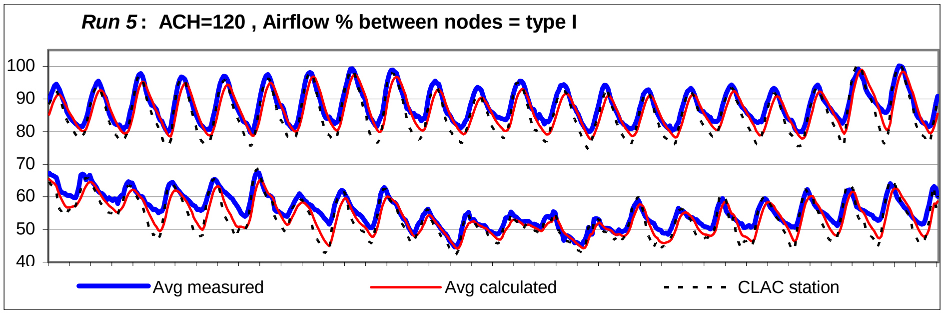
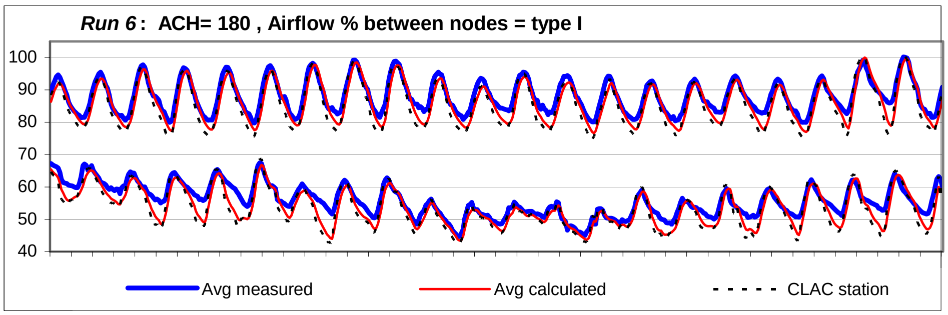


Figure 5.10a Second Calibration Runs for the Courtyard Microclimate FD Model with 6 ACH Rates for the Courtyard, Along with Type I Air Change Rates for its Upper and Lower Nodes (70% upper & 30% lower).

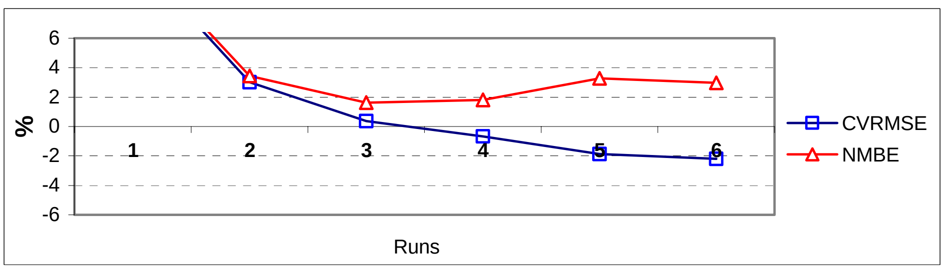


	CVRMSE	NMBE
AUG	-1.9	3.3
JAN	-3.6	5.4

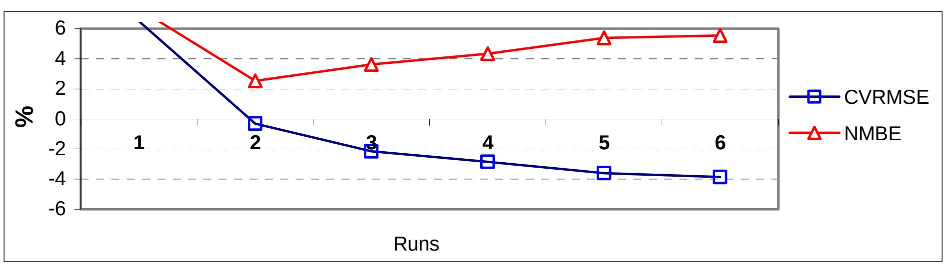


AUG	-2.2	3.0
JAN	-3.9	5.5

ACH = 100 ACH Airflow % per node = Type I



Summer



Winter

Run 1	5 ACH	Airflow % between nodes = type I
Run 2	20 ACH	Airflow % between nodes = type I
Run 3	40 ACH	Airflow % between nodes = type I
Run 4	60 ACH	Airflow % between nodes = type I
Run 5	120 ACH	Airflow % between nodes = type I
Run 6	180 ACH	Airflow % between nodes = type I

Figure 5.10a (continued).

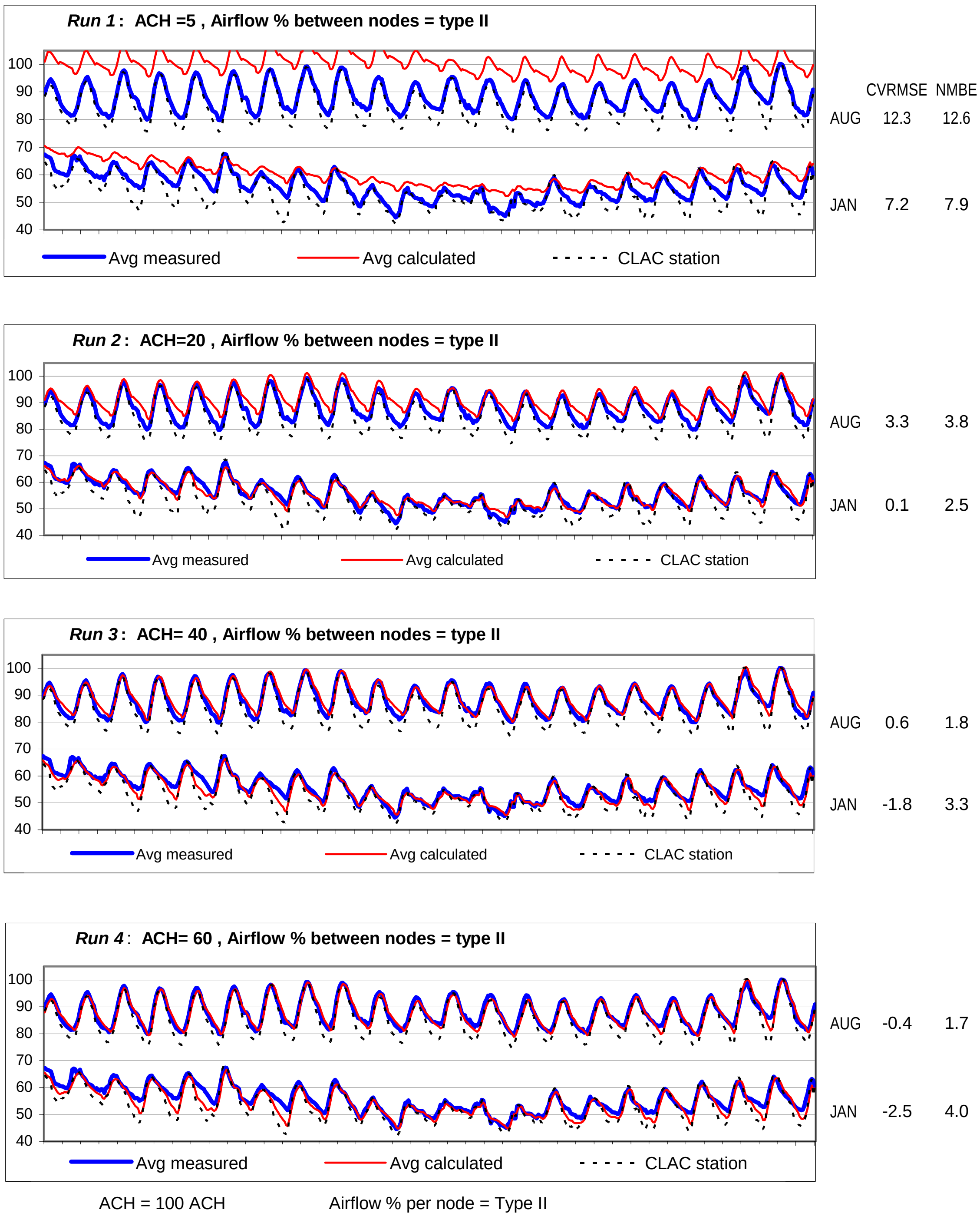
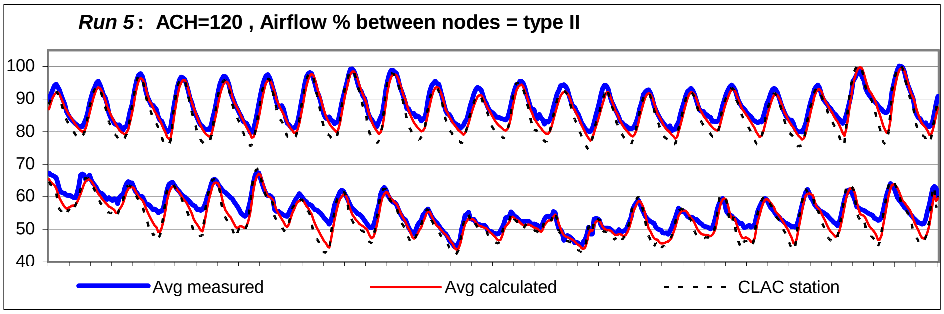
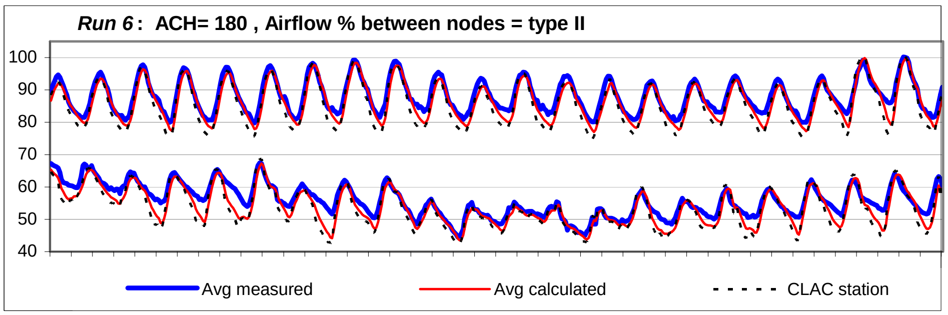


Figure 5.10b Second Calibration Runs for the Courtyard Microclimate FD Model with 6 ACH Rates for the Courtyard, Along with Type II Air Change Rates for its Upper and Lower Nodes (90% upper & 10% lower).

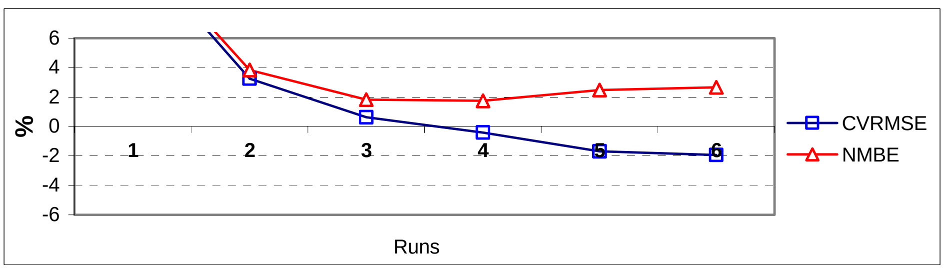


	CVRMSE	NMBE
AUG	-1.7	2.5
JAN	-3.2	5.0

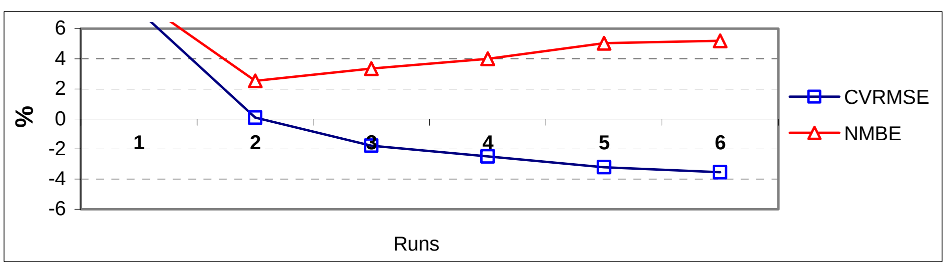


AUG	-1.9	2.7
JAN	-3.5	5.2

ACH = 100 ACH Airflow % per node = Type II



Summer



Winter

Run 1	5	ACH	Airflow % between nodes = type II
Run 2	20	ACH	Airflow % between nodes = type II
Run 3	40	ACH	Airflow % between nodes = type II
Run 4	60 ACH		Airflow % between nodes = type II
Run 5	120 ACH		Airflow % between nodes = type II
Run 6	180 ACH		Airflow % between nodes = type II

Figure 5.10b (continued)

Figure 5.10a shows the first six runs for the six ACH rates with Type I airflow percentage between nodes, and Figure 5.10 b shows the second six runs for the six ACH rates with Type II airflow percentage between nodes. Among these twelve runs an estimated ACH of 35 (a point between 20 ACH & 40 ACH runs) for both Types I & II air change percentage showed the best CV(RMSE) & NMBE results considering summer and winter periods.

The simulated courtyard microclimate hourly temperatures resulting from a run of 35 ACH with Type II air flow percentage between nodes were then used in the DOE-2 simulations for the interior zones in the case study house. Figure 5.11 shows the hourly simulated versus the measured courtyard microclimate dry-bulb temperature along with the measured rooftop dry-bulb temperature during the summer and winter monitoring periods. These data were used to produce the 24 hours temperature profile plots in Figure 5.12.

It is worth noting the following factors affecting the calibration results for the FD model against the measured data:

1. Measured cloud cover data were not available. Therefore, an average based on IWEC data for each of the monitoring periods was used in the formulas calculating the long wave radiation from wall and floor surfaces.
2. Wind data were not available for many hours (11% of the summer and 34% of the winter monitoring periods). Therefore, the data were estimated by copying the wind data records of the previous day.
3. The monitored temperatures for the courtyard were taken near the courtyard walls, while the FD model calculates a lumped air node temperature that represents the average of the courtyard. Hence, only one-dimensional effects were captured by the model.
4. Rooftop temperature data were used for the airflow from the street entering through the house entry gate to the courtyard lower air node. Unfortunately, the street had different temperatures from the rooftop which were not recorded.

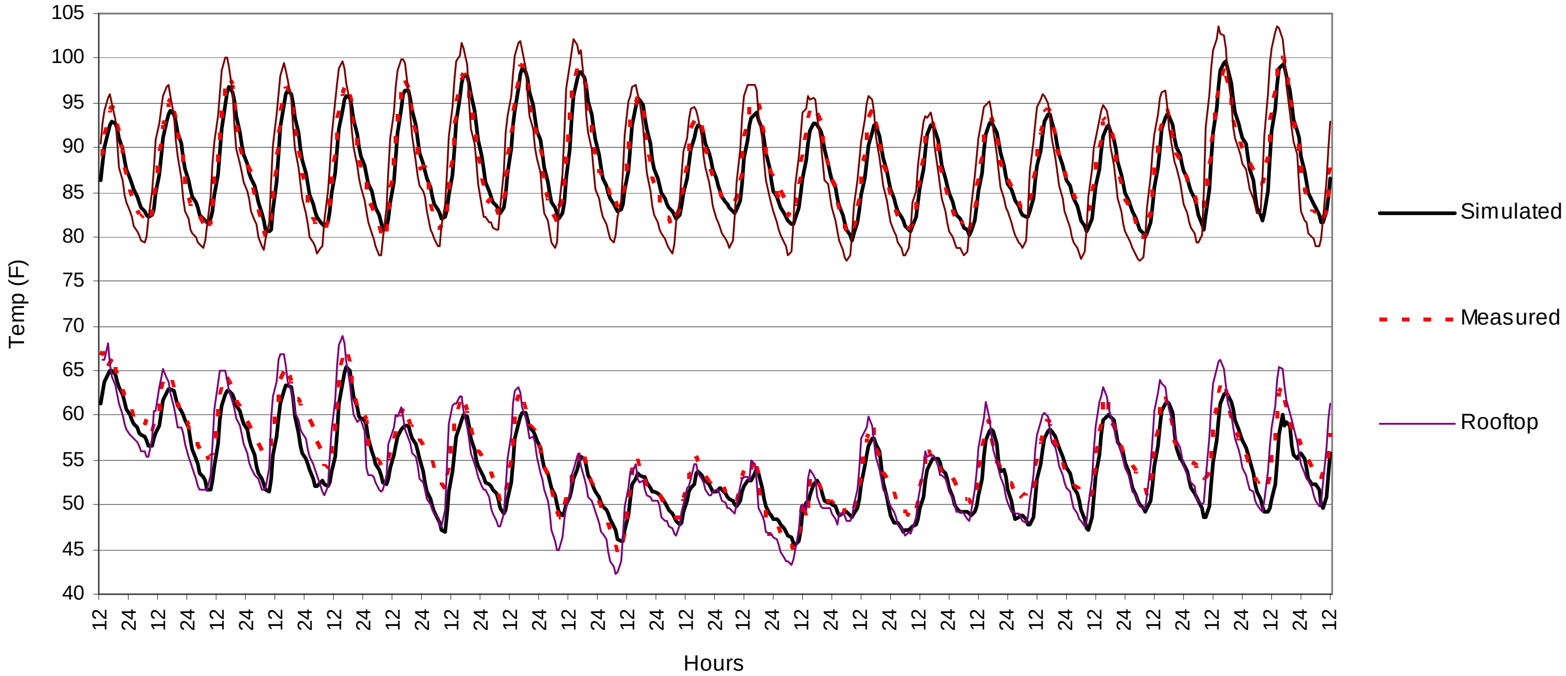


Figure 5.11 Hourly Simulated Versus Measured Courtyard Microclimate with Rooftop Temperature Records Time Series Plots During the Summer and Winter Monitoring Periods.

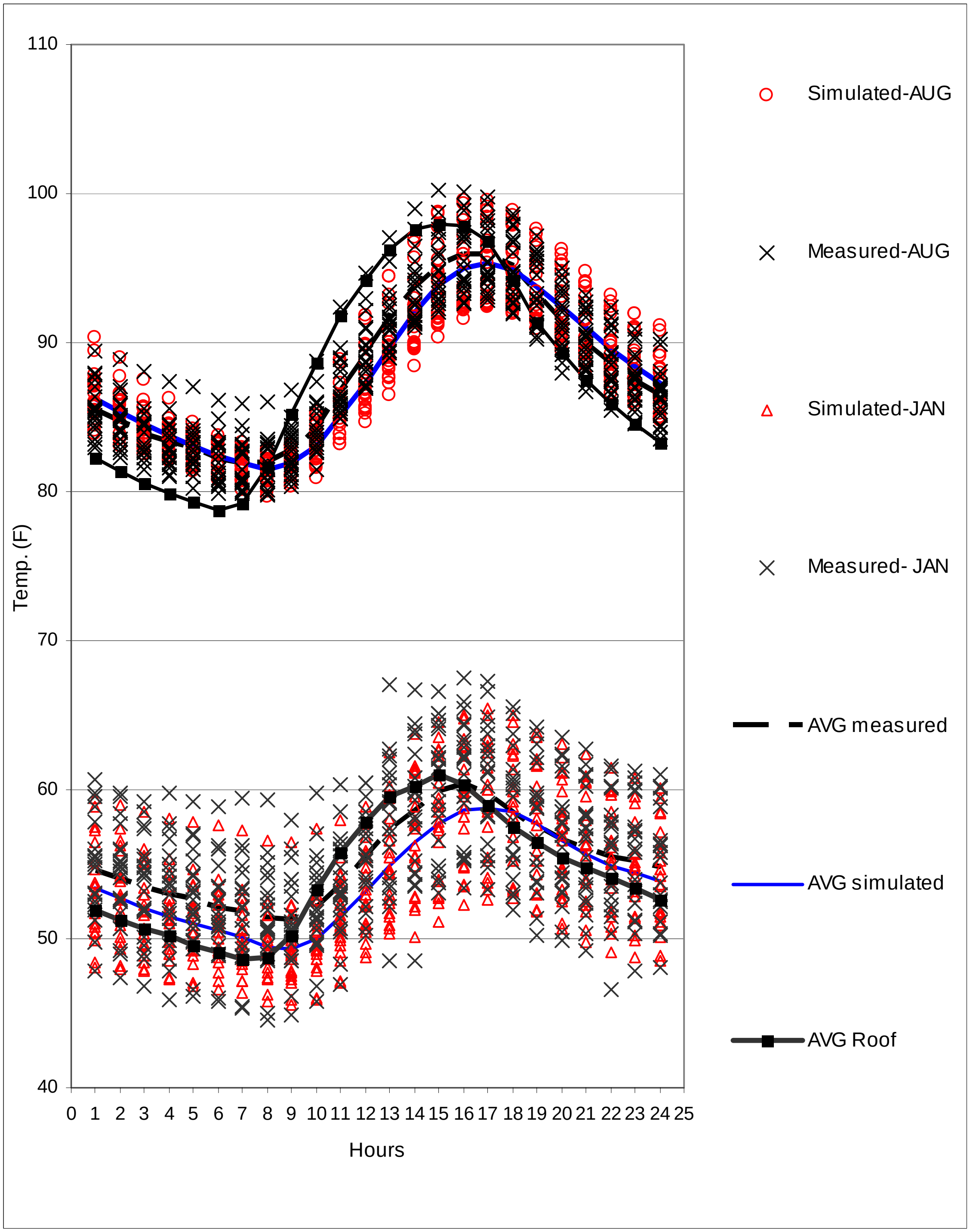


Figure 5.12 24 Hours Temperature Profiles Showing Simulated Versus Measured Courtyard Microclimate with Rooftop Temperatures during the Summer and Winter Monitoring Periods.

Figure 5.12 presents 24 hours temperature profiles showing simulated versus measured courtyard microclimate along with rooftop temperatures during the summer and winter monitoring periods.

During the summer monitoring period:

- The average simulated DB temperatures were lower in magnitude than the average measured by ~ 2 F between 9 am and 6 pm and higher by about 1 F the rest of the hours, while having a time lag of less than 1 hour.
- The courtyard simulated and measured average temperatures as compared to the average rooftop temperatures showed to be lower (reaching ~-4F) around the peak hours during the daytime and higher (reaching ~+5F) around the depression hours during the nighttime, while having a time lag shift between the rooftop and the courtyard measured microclimate of about 1.5 hours.

During the winter monitoring period:

- The average simulated DB temperatures were lower in magnitude than the average measured by ~ 2 to 3 F during the day except between 6 pm and 9 pm where both were identical, , while having a time lag of less than 1 hour.
- The courtyard simulated and measured average temperatures as compared to the average rooftop temperatures showed to be lower between 9 am and 4 pm (reaching -2 F) and higher for the rest of the hours (reaching +3 F), while having a time lag shift between the rooftop and the courtyard measured microclimate of about 1 hour.

5.4 Sensitivity Runs for the FD Courtyard Microclimate Model

In the previous calibration process the model showed a response to the applied modifications in the ACH rates (NMBE and CV(RMSE) changed up to 2%) as well as the thermal mass (NMBE and CV(RMSE) changed up to 1%). In this section, six sets of sensitivity runs were applied to the courtyard FD model. The first set varied the courtyard ACH considering the hourly wind speed, the second set varied the courtyard ground temperature, the third set varied the courtyard walls and floor emissivity, the fourth set varied the courtyard walls and floor absorptivity, and the fifth set varied the cloud cover, and the sixth set varied the ambient air temperature. In all sets of sensitivity runs, except for the courtyard ACH set, the courtyard had a 35 ACH along with Type I air change % per Node.

The range of the temperature difference between the courtyard microclimate and the rooftop will be used as a reference bench mark in the comparison between the sensitivity runs, other than the NMBE and the CV(RMSE) indices. Plots that zoom on the 3 hottest days and 4 coldest days of the year will be produced for this purpose.

Figures 5.4a and 5.5a show plots for the rooftop and the courtyard microclimate temperatures along with the difference between them during the summer and the winter monitoring periods respectively. The plots show that in the summer the difference reaches about 5 F during the day and 4 F during the night. In the winter this difference reaches about 4 F during the day and during the night.

The comparison between the resulting temperatures due to a change applied to a variable in a sensitivity run will be based on these microclimatic differences in the sense that if the temperature difference between two comparative runs was equal to 50% of the microclimatic differences then it will be noted that the model was significantly sensitive to this variable. The following sections present comments and graphs on each set of the sensitivity runs.

It is worth noting that the sensitivity runs may be classified under two sets of categories:

- The first set of sensitivity runs are related to the climatic variables (ambient temperature - cloud cover – airflow rates – ground temperature) and it is directed towards the validity of the FD model performance.
- The second set of sensitivity runs are related to the thermal characteristics of the courtyard envelope (absorptivity, emissivity, mass) and it is directed towards the sensitivity of the FD model towards these thermal characteristics.

In the review of literature I was not able to locate experiments on varying the courtyard thermal properties or design variables to test the resulting thermal performance. Thus the output results from the sensitivity runs had no previous records to be compared with and thus could not be verified.

5.4.1 First Sensitivity Run: Courtyard ACH Wind Speed Factor

An index that accounts for the wind speed factor was introduced to be multiplied by the hourly constant ACH rates that were used in the previous calibration runs. This was monitored by previous publications (Hall et al., 1999) that reported on wind-tunnel tests (i.e., they pointed out that the air speed above the courtyard has direct impact on the courtyard ACH rates). Thus, a range of indices were generated which considered hourly, daily, monthly, and annual records. These indices were as follows:

1. (10% of hourly wind speed)
2. (hourly wind speed / daily avg. wind speed)
3. (hourly wind speed / weekly avg. wind speed)
4. (hourly wind speed / monthly avg. wind speed)
5. (hourly wind speed / annual avg. wind speed)
6. (daily avg. wind speed / annual max daily avg. wind speed)
7. (weekly avg. wind speed / annual max weekly avg. wind speed)
8. (monthly avg. wind speed / annual max monthly avg. wind speed)

As these indices varied in their output as shown in Figure 5.13, they were reduced based on their similarity to four main sets of indices:

1. hourly wind speed / daily avg. wind speed, with a factor ranging from 0 to 3.5

2. hourly wind speed / monthly avg. wind speed, with a factor ranging from 0 to 3
3. weekly avg. wind speed / annual max weekly avg. wind speed, with a factor ranging from 0 to 2
4. daily avg. wind speed / annual max daily avg. wind speed, with a factor ranging from 0 to 1

These four sets of indices with the base case of a constant 35 ACH were applied to the calibrated courtyard microclimate model and the output including their CV(RMSE) and NMBE evaluations is shown in Figure 5.14. Results show that three of the four ACH indices showed very similar results to the base case, and that the fourth ACH index produced courtyard microclimates having NMBE and CV(RMSE) values that varied within up to 4% from that of the base case, which may be considered as insignificant. Additional runs for investigating higher ACH factors were made on multiples of the first ACH factor (i.e., hourly wind speed / daily avg. wind speed) that had the highest range of ACH factor ranging from 0 to 3.5. Figure 5.15a shows two additional runs that were made by multiplying this ACH factor by 1.5 and by 2. The run that was made by doubling the ACH factor (i.e., ACH factor ranging from 0 to 7) showed an excellent match between the simulated and the measured winter air temperatures having an NMBE of 0.2 and a CV(RMSE) of 3.2.

Since the FD model showed that the applied range of ACH indices had insignificant impact on the resulting courtyard microclimate temperatures, therefore future work may need to be viewed with comparisons to higher levels of ACH rates in open spaces (i.e., streets, open yards,…etc.) that does not contain a microclimatic phenomenon such as the one demonstrated by the semi-enclosed space of the courtyard.

Figures 5.15b and 5.15c shows close-ups (from Figure 5.14) of the hottest 3 days and coldest 4 days of the year respectively. During the hottest days, the first index showed to be higher than the other indices by about 3 F (starting from noon until the lowest temperature of the day) as well as having a time lag. The other three indices were similar to the base case with few exceptional peaks (reaching > 6 F over the base case) during the night hours. During the coldest days, the four indices showed to be generally similar (except for the lowest temperatures of the day where the difference in temperatures was about 2 F). Yet the first index was the closest to the base case and to the measured data. It may be concluded that the model is likely sensitive to the applied ACH indices.

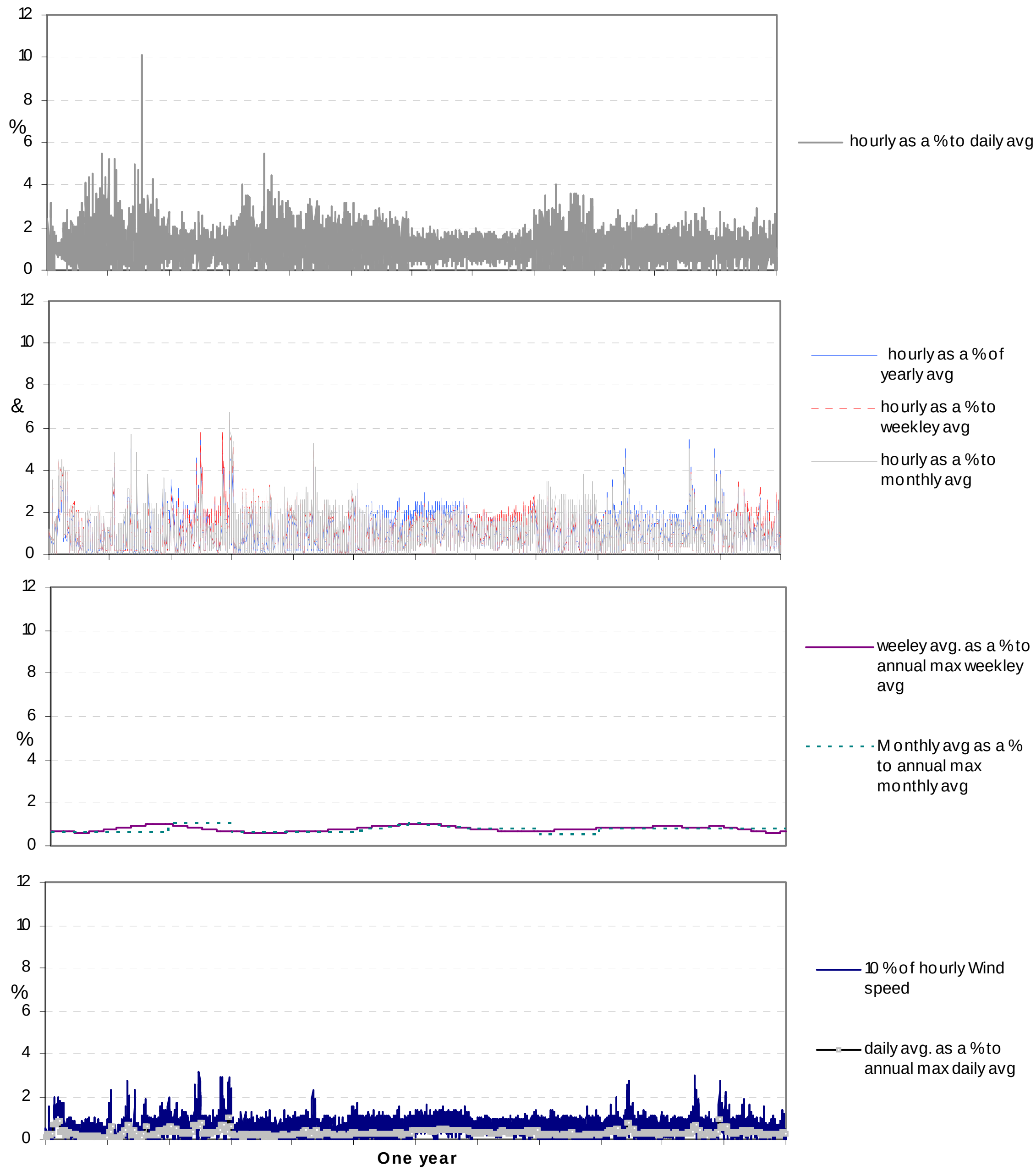


Figure 5.13 Classifications of Four Basic Synthesized Patterns of Wind Speed Factor Indices.

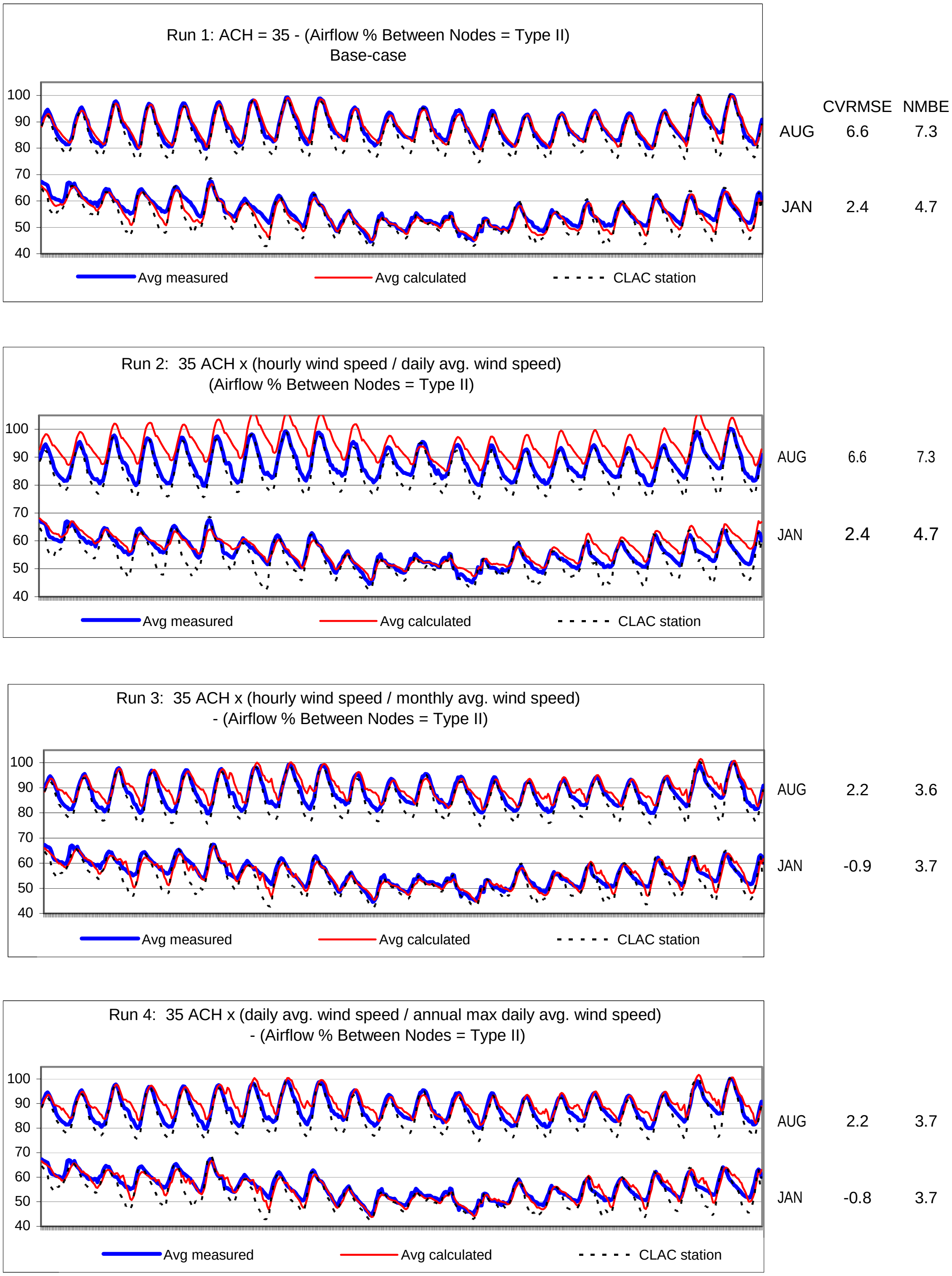
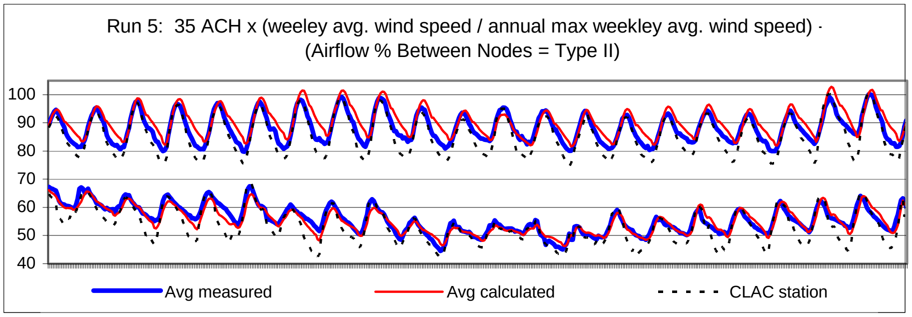
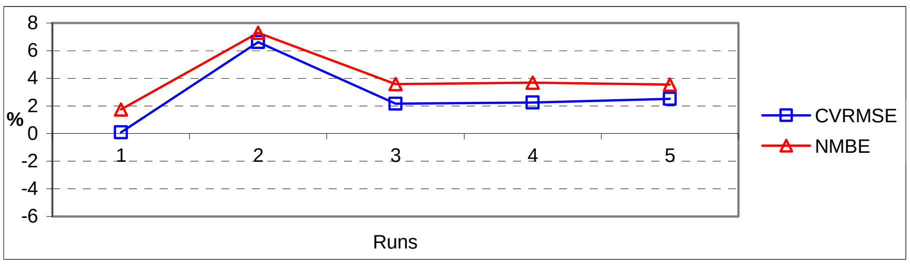


Figure 5.14 Sensitivity Runs for the Courtyard Microclimate FD model Showing Base Case ACH with 4 ACH Factors.

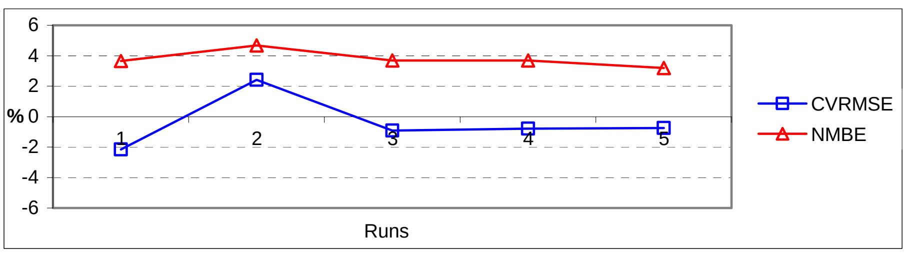


AUG 2.5 3.5

JAN -0.8 3.2



AUG

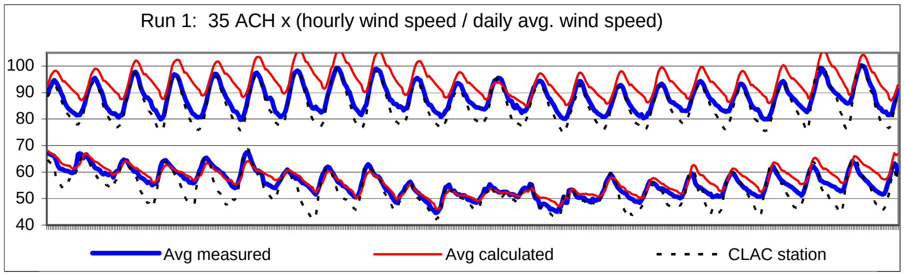


JAN

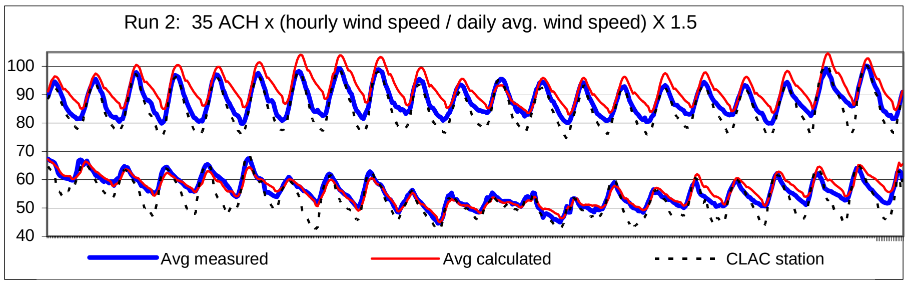
Run 1	35 ACH (Base-case)
Run 2	35 ACH x (hourly wind speed / daily avg. wind speed)
Run 3	35 ACH x (hourly wind speed / monthly avg. wind speed)
Run 4	35 ACH x (daily avg. wind speed / annual max daily avg. wind speed)
Run 5	35 ACH x (weeley avg. wind speed / annual max weekley avg. wind speed)
	Airflow % between nodes = type II (70%)

.

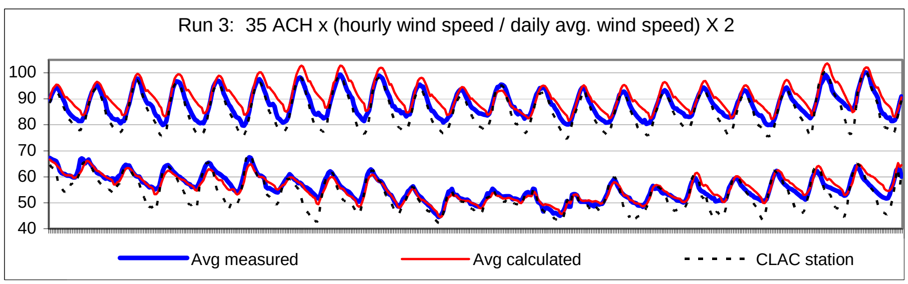
Figure 5.14 (Continued).



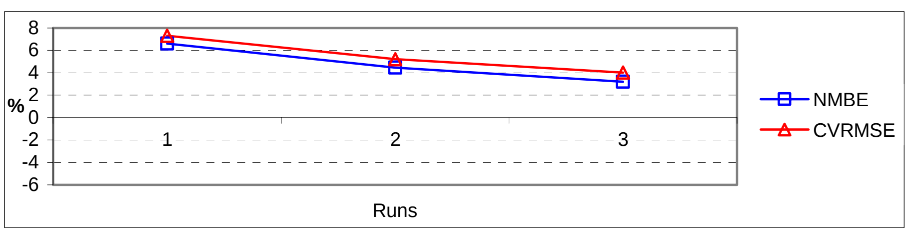
AUG	6.6	7.3
JAN	2.4	4.6



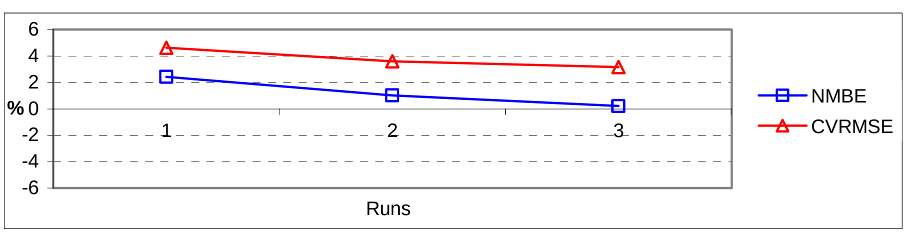
AUG	4.5	5.2
JAN	1.0	3.6



AUG	3.2	4.0
JAN	0.2	3.2



AUG



JAN

Run 1	35 ACH x (hourly wind speed / daily avg. wind speed)
Run 2	35 ACH x (hourly wind speed / daily avg. wind speed) X 1.5
Run 3	35 ACH x (hourly wind speed / daily avg. wind speed) X 2

Airflow % between nodes = type II (70%)

Figure 5.15a Sensitivity Runs for the Courtyard Microclimate FD Model Showing Multiplications to the First ACH Factor.

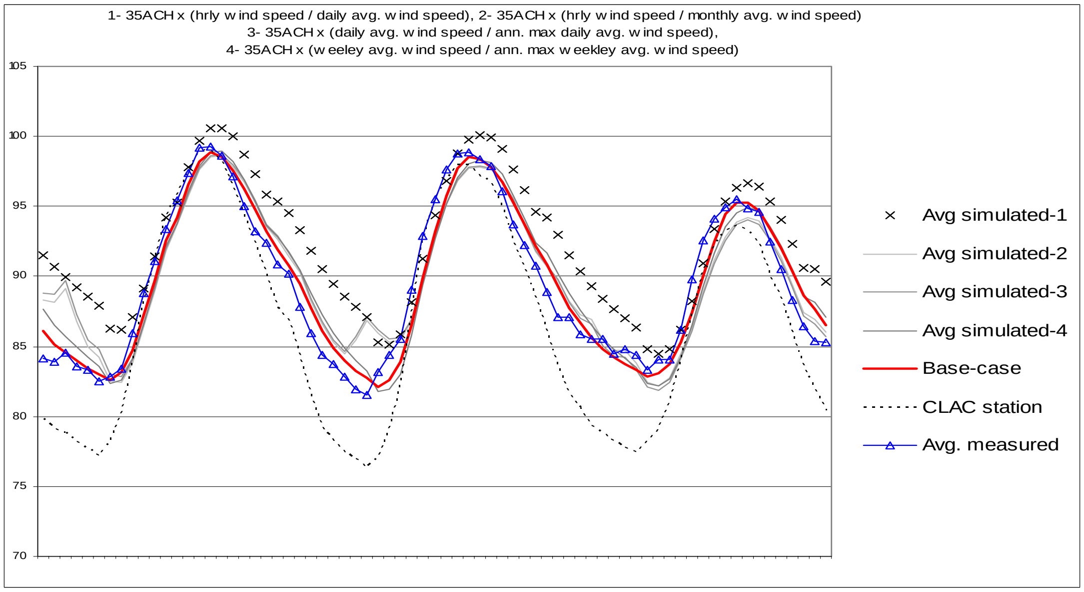


Figure 5.15b Sensitivity Runs for the Courtyard Microclimate FD Model with Base case ACH and 4 ACH Factors, Showing Close-up of Three Summer Days.

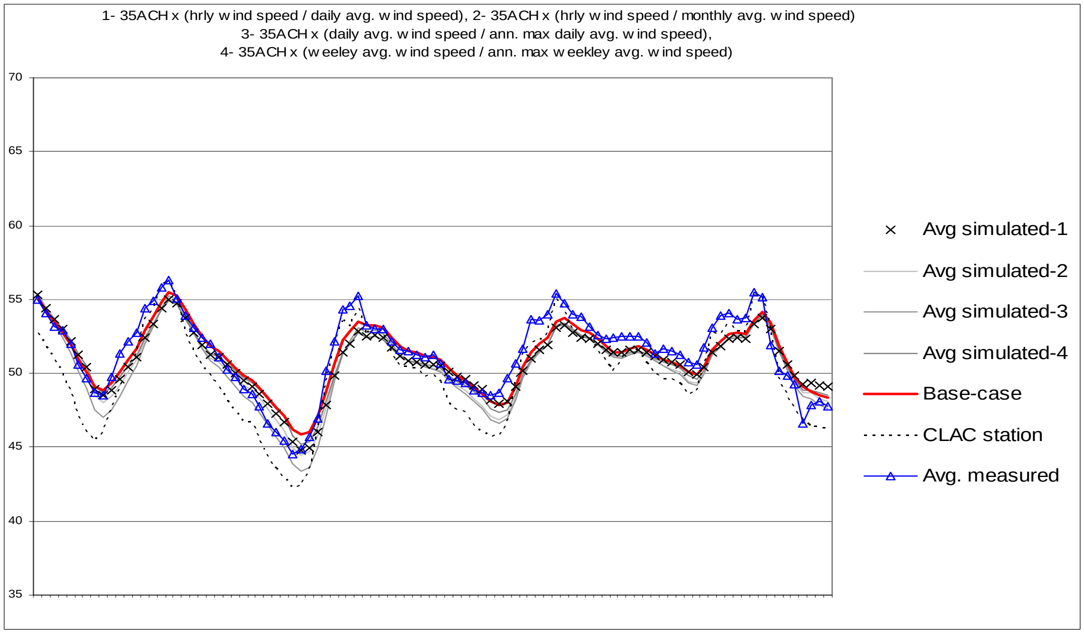


Figure 5.15c Sensitivity Runs for the Courtyard Microclimate FD model with Base case ACH and 4 ACH Factor , Showing Close-up of Four Winter Days.

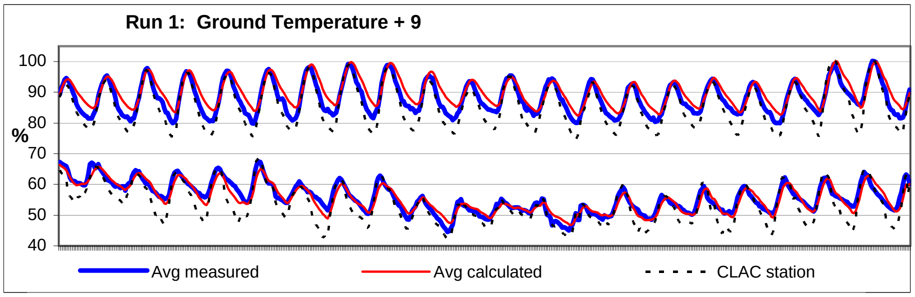
5.4.2 Second Sensitivity Run: Courtyard Ground Temperature

The monthly courtyard ground temperatures were varied to test its impact on the resulting courtyard microclimate simulation. In the first run the courtyard ground temperature was increased by 9 degrees Fahrenheit, while in the second run the courtyard microclimate was decreased by 9 degrees Fahrenheit, and both were compared against the original run with the 'as is' ground temperature. The outputs are presented with their CV(RMSE) and NMBE evaluations in Figure 5.16a. Results show that for the applied ground temperature variations the effect on the courtyard microclimate varied within 1% from the original NMBE and CV(RMSE) values, which may be considered as insignificant.

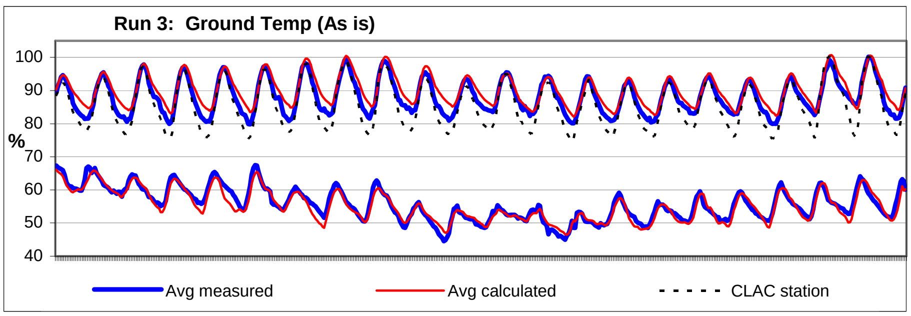
Figures 5.16b and 5.16c show a close-up of the hottest and coldest 4 days of the year respectively. During the hottest days, a ground temperature of 9 degrees less than normal and the ground temperatures 9 degrees greater than normal produced very similar air temperatures with the later being higher during the peak hours by about 2 F. Both showed lower temperatures during heating hours and higher temperatures during the cooling hours than the base case. Yet the base case was the closest to the measured data. During the coldest days, the four indices were very similar (difference in temperatures was less than 1.5F). Thus the model was not significantly sensitive to this variable.

5.4.3 Third Sensitivity Run: Courtyard Walls and Floors Emissivity

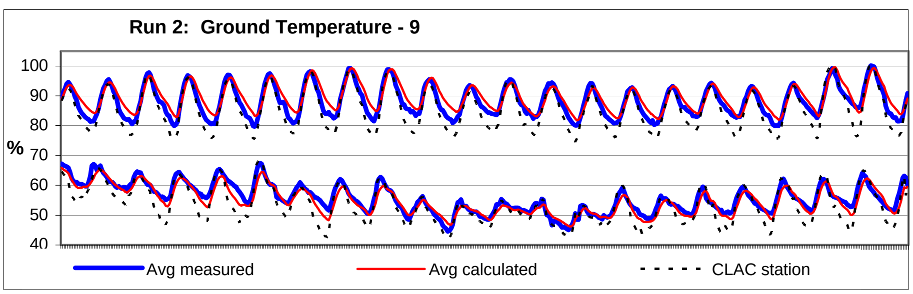
The courtyard walls and floors emissivity values were varied to test their impact on the resulting courtyard microclimate temperatures. In the first run the emissivity of the courtyard floor and walls were set to their real values, while in the second run these values were reduced by 20%, and in the third run these values were reduced further by 40%. The outputs were presented with their CV(RMSE) and NMBE evaluations in Figure 5.17a. Results showed that for the applied emissivity variations the effect on the courtyard microclimate varied within 1% of the original NMBE and CV(RMSE) values, which may be considered as insignificant.



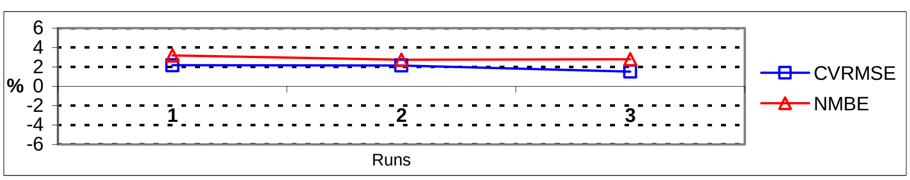
	CVRMSE	NMBE
AUG	2.2	3.2
JAN	-0.5	3.0



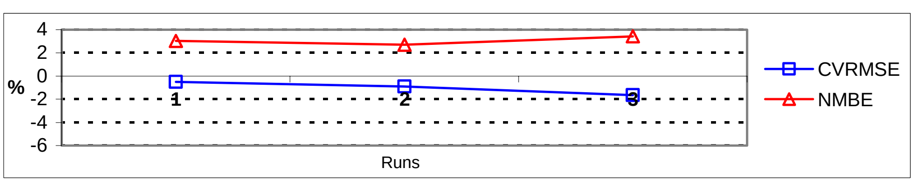
AUG	2.2	2.7
JAN	-0.9	2.7



AUG	1.5	2.8
JAN	-1.6	3.4



AUG



JAN

Run 1	Ground Temperature + 9
Run 2	Ground Temperature - 9
Run 3	Ground Temperature (as is)

Figure 5.16a Sensitivity Runs for the Courtyard Microclimate FD Model with Ground Temperature ± 9°F of its Real Value.

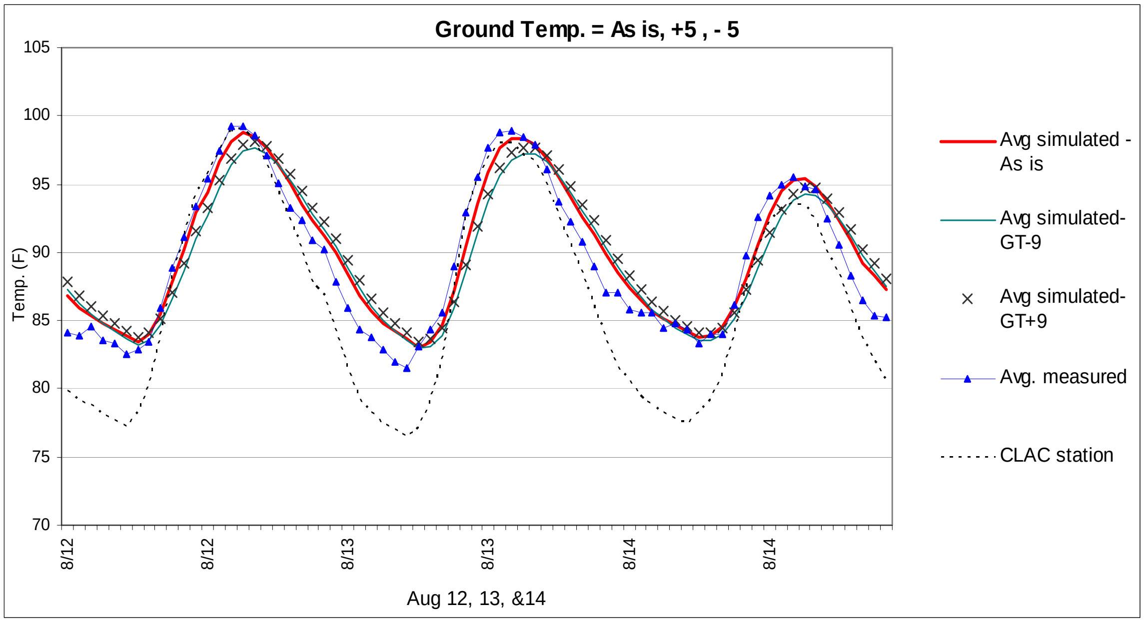


Figure 5.16b Sensitivity Runs for the Courtyard Microclimate FD Model with Ground Temperature ± 9°F of its Real Value, Showing Close-up of Three Summer Days.

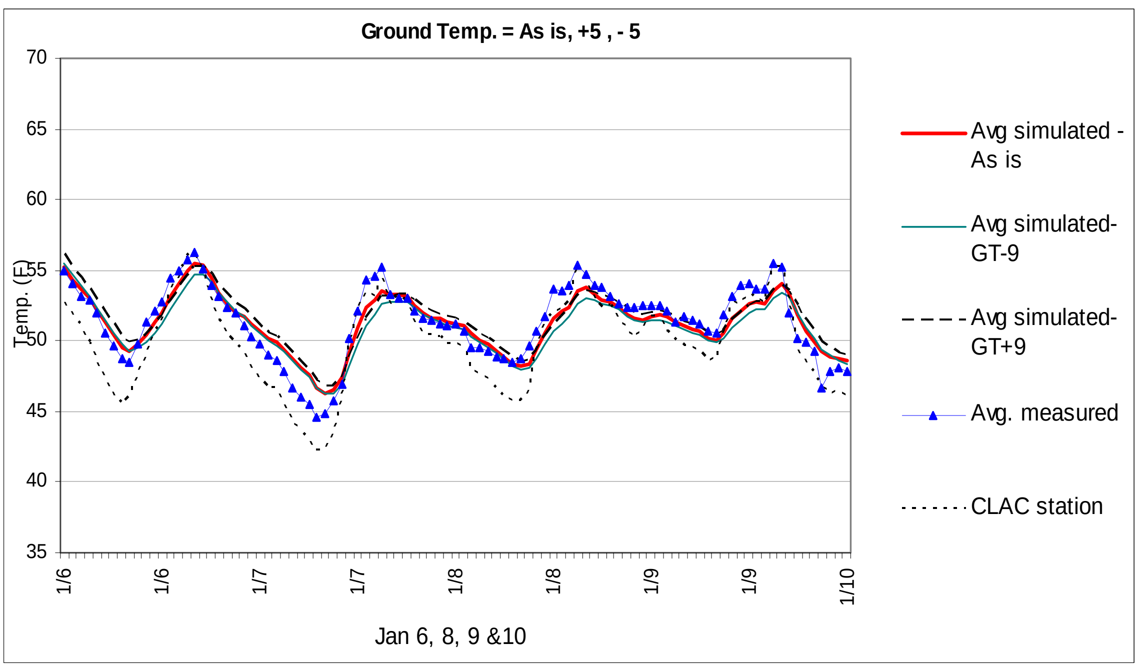
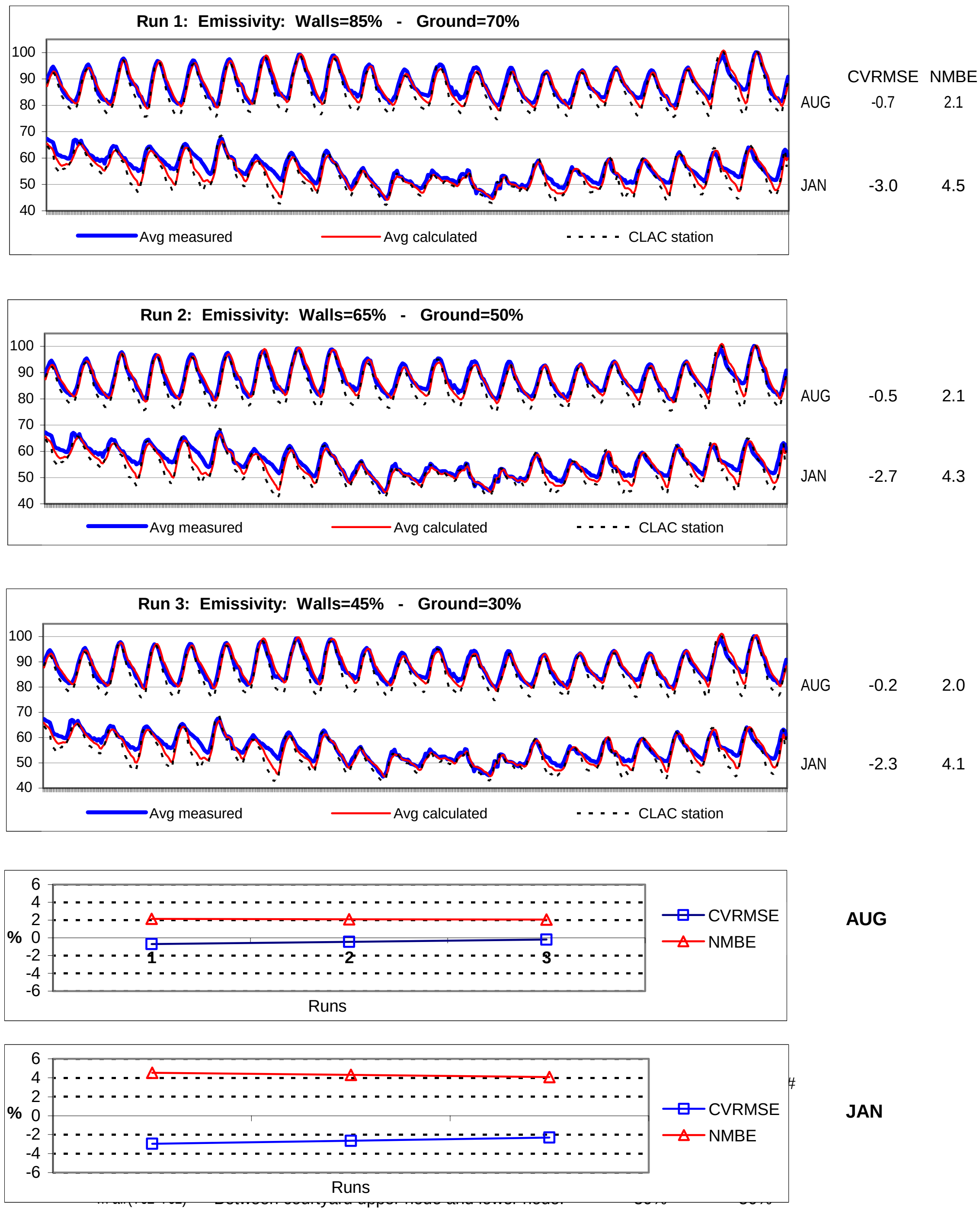


Figure 5.16c Sensitivity Runs for the Courtyard Microclimate FD Model with Ground Temperature ± 9°F of its Real Value, Showing Close-up of Four Winter Days.



Run 1 Emissivity: walls=0.85 - Ground=0.70 (As is)
Run 2 Emissivity: walls=0.65 - Ground=0.50 (Less 20%)
Run 3 Emissivity: walls=0.45 - Ground=0.30 (Less 40%)

Figure 5.17a Sensitivity Runs for the Courtyard Microclimate FD Model with Walls and Floors Emissivity Reduced 20% and 40 % Less Than its Real Value.

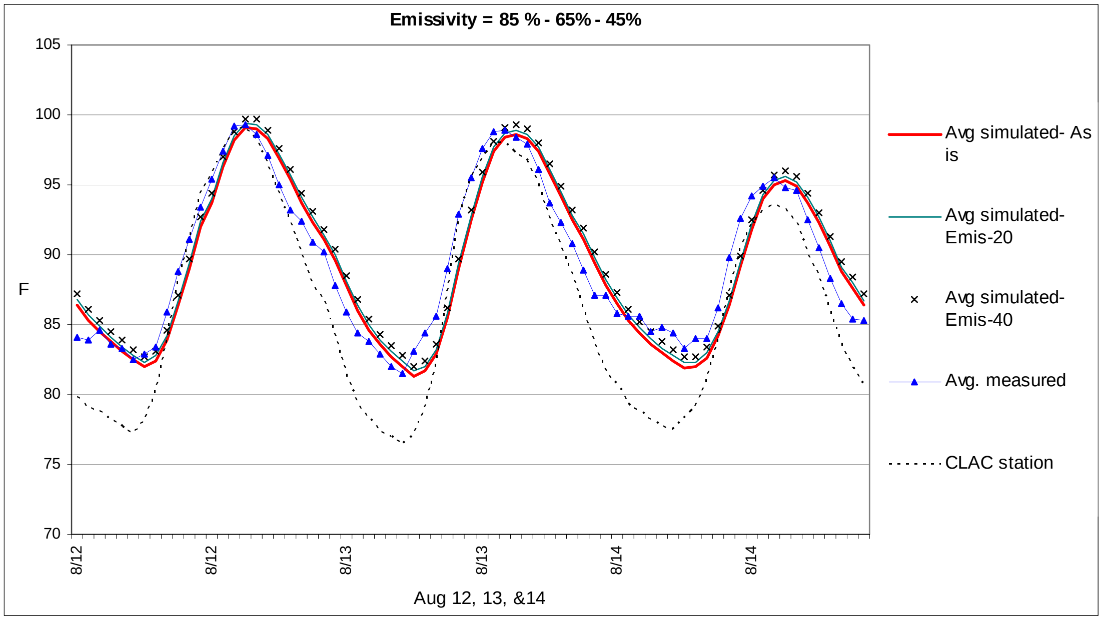


Figure 5.17b Sensitivity Runs for the Courtyard Microclimate FD Model with Walls and Floors Emissivity Reduced 20% and 40 % Less Than its Real Value, Showing Close-up of Three Summer Days.

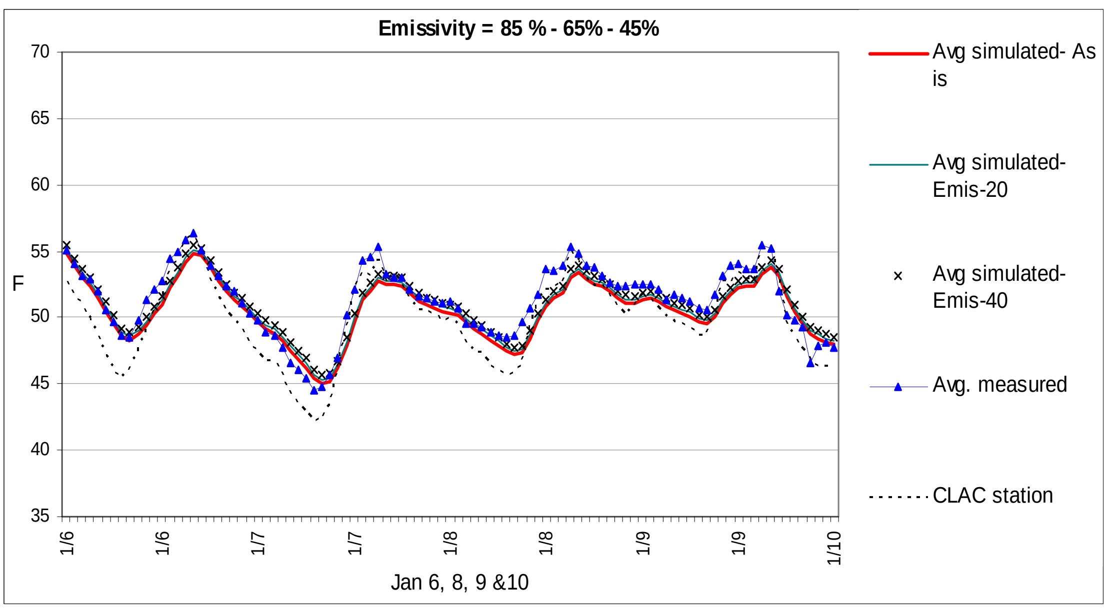


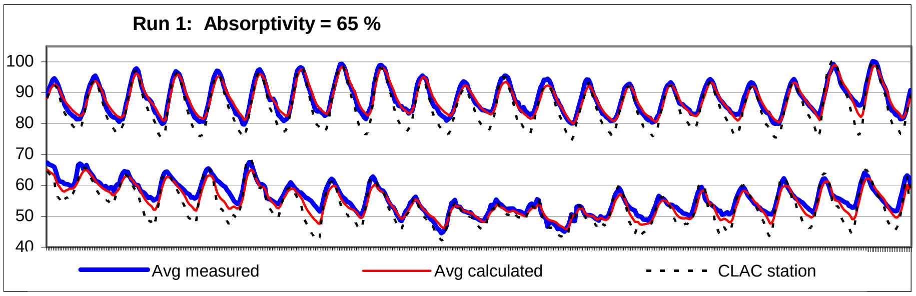
Figure 5.17c Sensitivity Runs for the Courtyard Microclimate FD Model with Walls and Floors Emissivity Reduced 20% and 40 % Less Than its Real Value, Showing Close-up of Four Winter Days.

Figures 5.17b and 5.17c show a close-up of the hottest and coldest 4 days of the year respectively. During the hottest days, the runs with reduced emissivity by 20% and 40% produced very similar air temperatures to the base case (both being higher than the base case by less than 1.5 F during the peak and the depressions hours). During the coldest days, the simulations with the applied two emissivity values showed a similar performance (difference in simulated temperatures was less than 1.5F). Thus the model did not appear to be significantly sensitive to this variable.

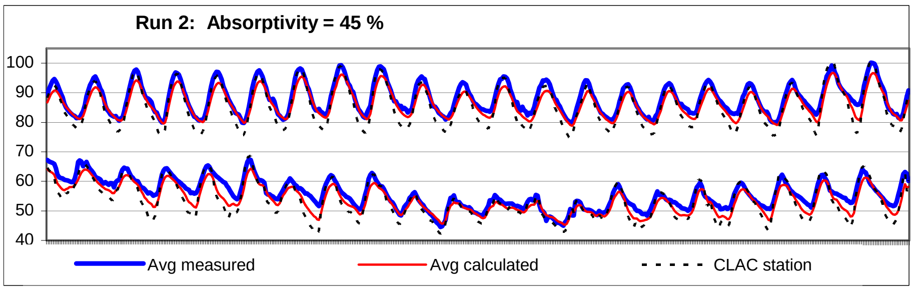
5.4.4 Fourth Sensitivity Run: Courtyard Walls and Floors Absorptivity

The courtyard walls and floors absorptivity values were varied to test their impact on the resulting courtyard microclimate temperatures. In the first run the absorptivity of the courtyard floor and walls were set to real values, while in the second run these values were reduced by 20%, and in the third run these values were increased by 20%. The outputs were presented with their CV(RMSE) and NMBE evaluations in Figure 5.18a. Results showed that for the applied absorptivity variations the effect on the courtyard microclimate varied within 2% of the original NMBE and CV(RMSE) values, which may be considered as insignificant.

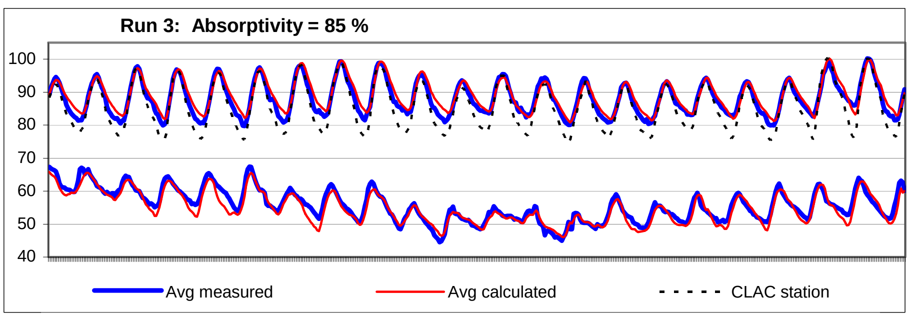
However, Figures 5.18b and 5.18c show a close-up of the hottest and coldest 3&4 days of the year respectively. During the hottest days, the run with the absorptivity value increased by 20% (i.e., 85%) produced simulated temperatures that were similar to the base case during the heating hours and hotter than the base case during the cooling hours. The run with the absorptivity value decreased by 20% (i.e., 45%) produced simulated temperatures that were less than the base case during all the hours by <3F. During the coldest days, the simulations with the two new absorptivity values (i.e., 45% & 85%) showed a similar performance to the base case (difference in simulated temperatures was less than 2F). Accordingly, the model may be labeled as significantly sensitive to absorptivity under the summer climate. During the winter this would not be valid, likely due to the existence of a cloud cover.



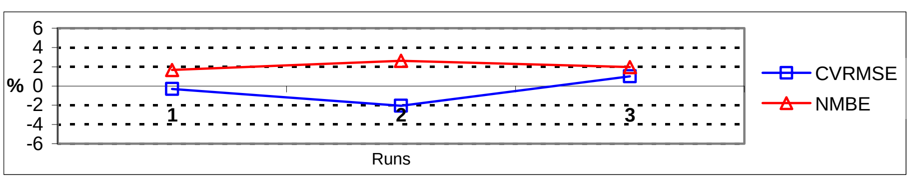
	CVRMSE	NMBE
AUG	-0.3	1.7
JAN	-2.3	3.6



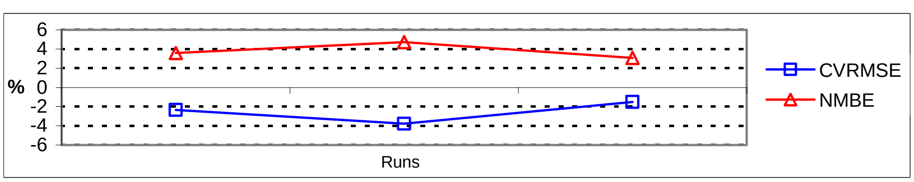
AUG	-2.1	2.6
JAN	-3.8	4.7



AUG	1.0	1.9
JAN	-1.5	3.1



AUG



JAN

Run 1	Absorptivity = 0.65	
Run 2	Absorptivity = 0.45	(Less 20%)
Run 3	Absorptivity = 0.85	(Pluss 20%)

Figure 5.18a Sensitivity Runs for the Courtyard Microclimate FD Model with Walls and Floor Absorptivity Reduced 20% and increased 20% of Its Real Value.

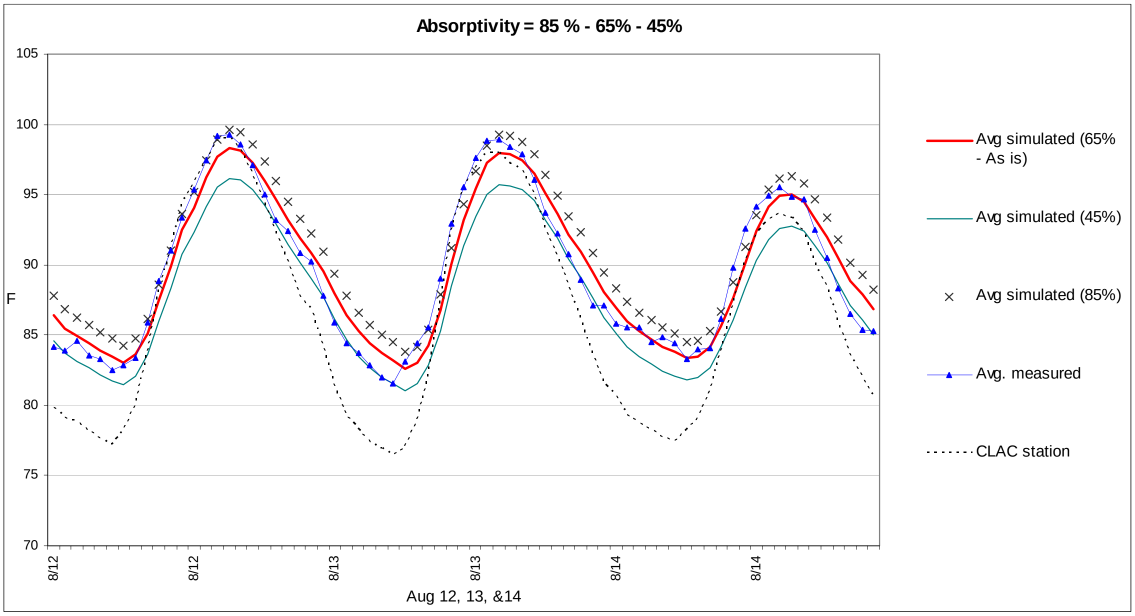


Figure 5.18b Sensitivity Runs for the Courtyard Microclimate FD Model with Walls and Floor Absorptivity Reduced 20% and Increased 20% of its Real Value, Showing Close-up of Three Summer Days.

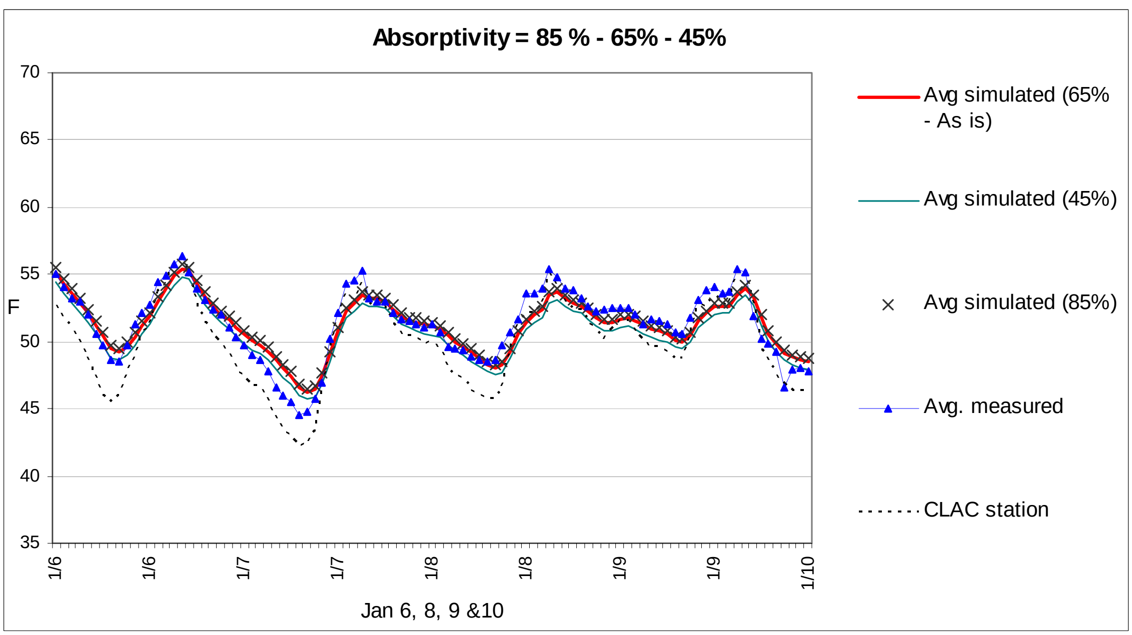


Figure 5.18c Sensitivity Runs for the Courtyard Microclimate FD Model with Walls and Floor Absorptivity Reduced 20% and Increased 20% of its Real Value, Showing Close-up of Four Winter Days.

5.4.5 Fifth Sensitivity Run: Cloud Cover

The ambient cloud cover values were varied to test their impact on the resulting courtyard microclimate temperatures. In the first run the cloud cover was set to 0%, in the second run it was set to 50%, and in the third run it was set to 100%. Yet the application of this variable in this set of runs is imaginary in its nature, since the cloud cover variable will be modified without affecting the solar radiation data. The outputs were presented with their CV(RMSE) and NMBE evaluations in Figure 5.19a. Results showed that for the applied three cloud cover variations their impact on the courtyard microclimate was between < 1% to < 4% for the resulting NMBE and CV(RMSE) values, which may be considered insignificant.

Figures 5.19b and 5.19c show a close-up of the hottest 3 days and coldest 4 days of the year respectively. During the hottest days, the runs while varying the cloud cover (0, 5, and 10) produced simulated temperatures that were similar (difference in simulated temperatures was less than 2 F). During the coldest days, the simulations with the applied cloud cover were also similar (difference in simulated temperatures was less than 2F). Thus it could be noted that the model was not sensitive to the cloud cover.

5.4.6 Sixth Sensitivity Run: Ambient Air Temperature

The ambient (i.e., rooftop) air temperature values were varied to test their impact on the resulting courtyard microclimate temperatures. In the first run the ambient air temperature was increased by 9 ^{o}F, while in the second run they were set to their real values, and in the third run these values were reduced by 9 ^{o}F. The outputs were presented with their CV(RMSE) and NMBE evaluations in Figure 5.20a. Results showed that for the applied temperature variations the effect on the courtyard microclimate varied between 10 to 20% of the original NMBE and CV(RMSE) values. The ambient air temperature showed the highest sensitivity among the tested other factors. Among six variables tested in the sensitivity runs the ambient air temperature was found to be very sensitive. These results agree with the argument mentioned in section 5.1.2 on Figures 5.4 a, b & c that recommended using the rooftop temperature records instead of the CLAC weather station records. In a different direction, these results support the accuracy of the relationship between the microclimate produced by the FD model and ambient air records.

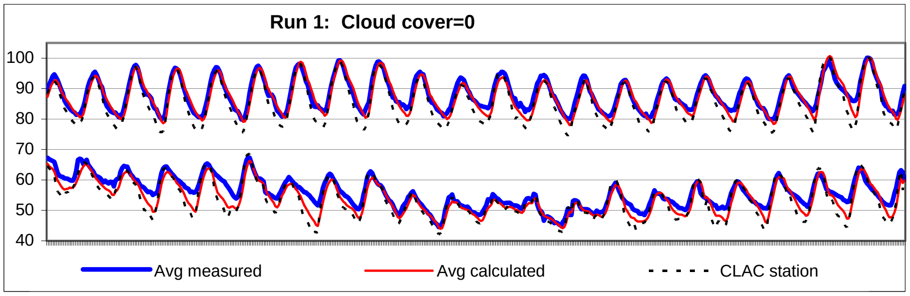
Figures 5.20b and 5.20c shows a close-up of the hottest 3 days and coldest 4 days of the year respectively. During the hottest and the coldest days, the runs while increasing and decreasing the rooftop temperature by 9F respectively produced significant higher and lower simulated temperatures respectively by >7F. Thus it may be noted that the model was very sensitive to the ambient air temperature under the summer and the winter climates.

In conclusion, the sensitivity runs showed that the model was sensitive to ACH rates and the envelope absorptivity. Also, it showed that the model was very sensitive to the ambient air temperatures.

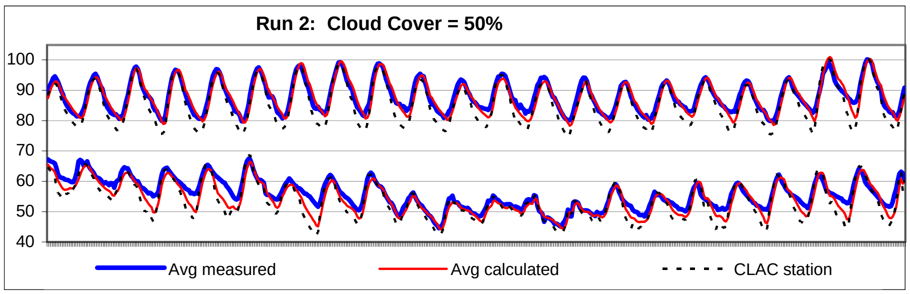
5.5 Calibrated DOE-2 Courtyard House Model with the FD Microclimate Weather File

This section presents results regarding how the simulated courtyard microclimate weather file generated by the FD model was applied to the DOE-2 simulation of the abstract courtyard house configuration that represents the case study courtyard house. This was investigated through a series of runs that were detailed in section 4.3.1.3 and described in Figure 4.6 and Table 4.2. These runs allowed for the comparison of a standard DOE-2 simulation for the courtyard house with the ambient weather file against a simulation that combines the ambient weather file with a courtyard microclimate weather file. In all the runs the comparison is between the measured temperatures for the reception hall at the ground floor of the actual house that opens onto the main courtyard, which is located between two courtyards: the main and the service, against the simulated temperatures of the southeast wing inner zone space of the abstract house model having one wall onto the courtyard at the ground floor.

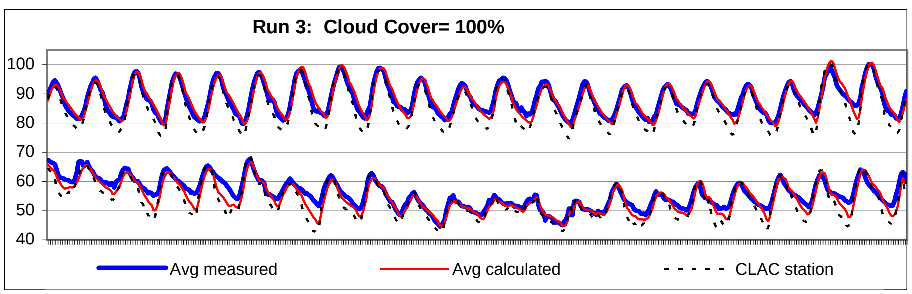
The runs focused on a summer monitoring period (August 5 to 26, 2001) and a winter monitoring period (December 28th, 2001 to January 19th, 2002). These runs showed a convergence deficiency in the DOE-2 program occurring on the 1st day of January, which made the calibration difficult.



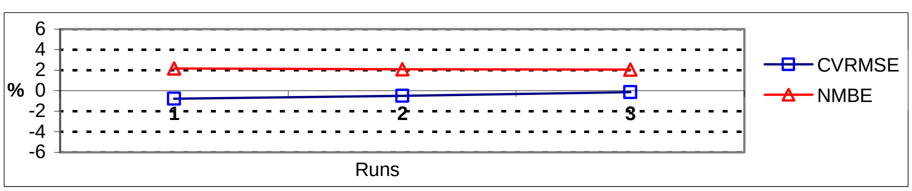
	CVRMSE	NMBE
AUG	-0.8	2.2
JAN	-3.4	4.8



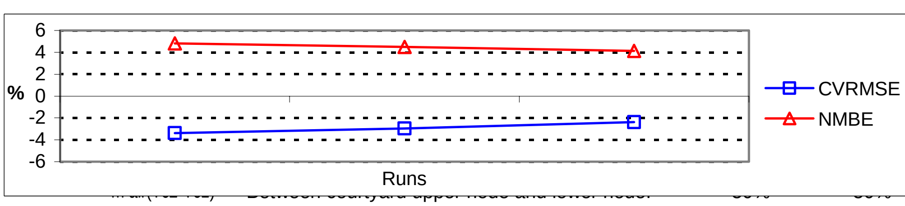
AUG	-0.5	2.1
JAN	-3.0	4.5



AUG	-0.1	2.0
JAN	-2.4	4.1



AUG



JAN

Run 1	Cloud Cover = 0 %
Run 2	Cloud Cover = 50 %
Run 3	Cloud Cover = 100 %

Figure 5.19a Sensitivity Runs for the Courtyard Microclimate FD Model While Varying the Cloud Cover (0, 50, & 100%).

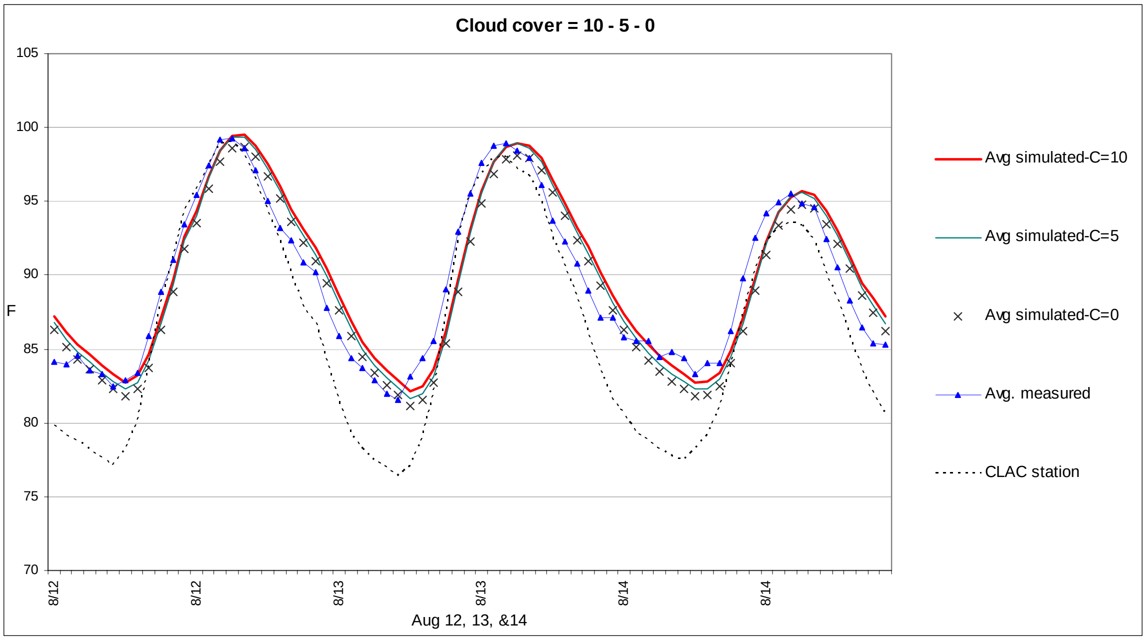


Figure 5.19b Sensitivity Runs for the Courtyard Microclimate FD Model while Varying the Cloud Cover (0, 50, & 100%), Showing Close-up of Three Summer Days.

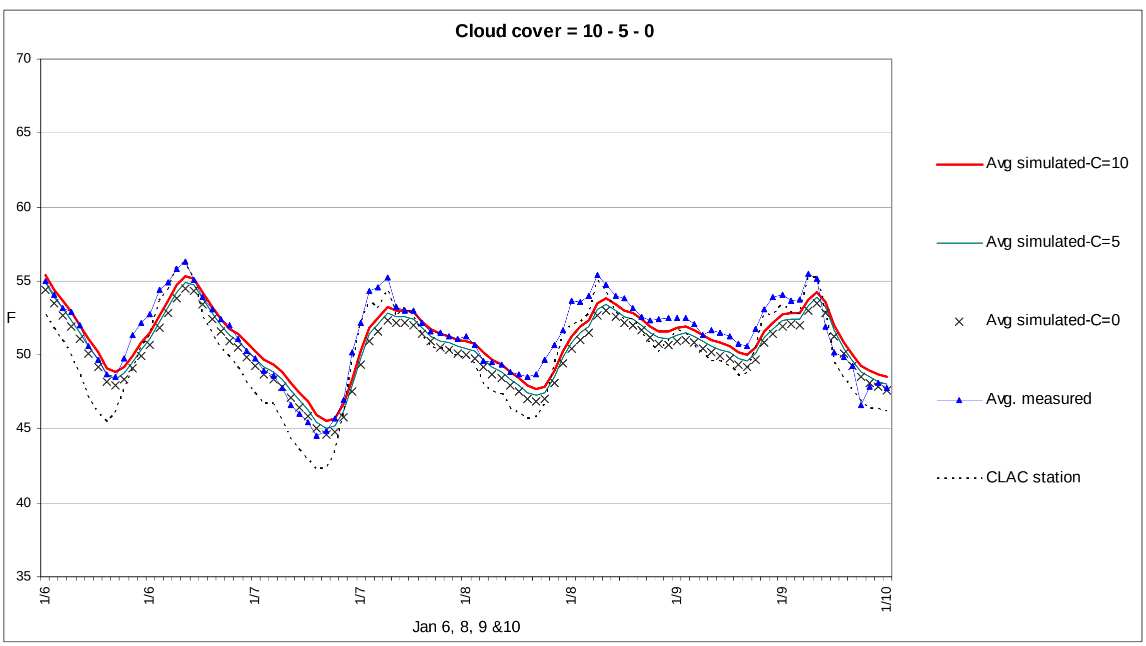
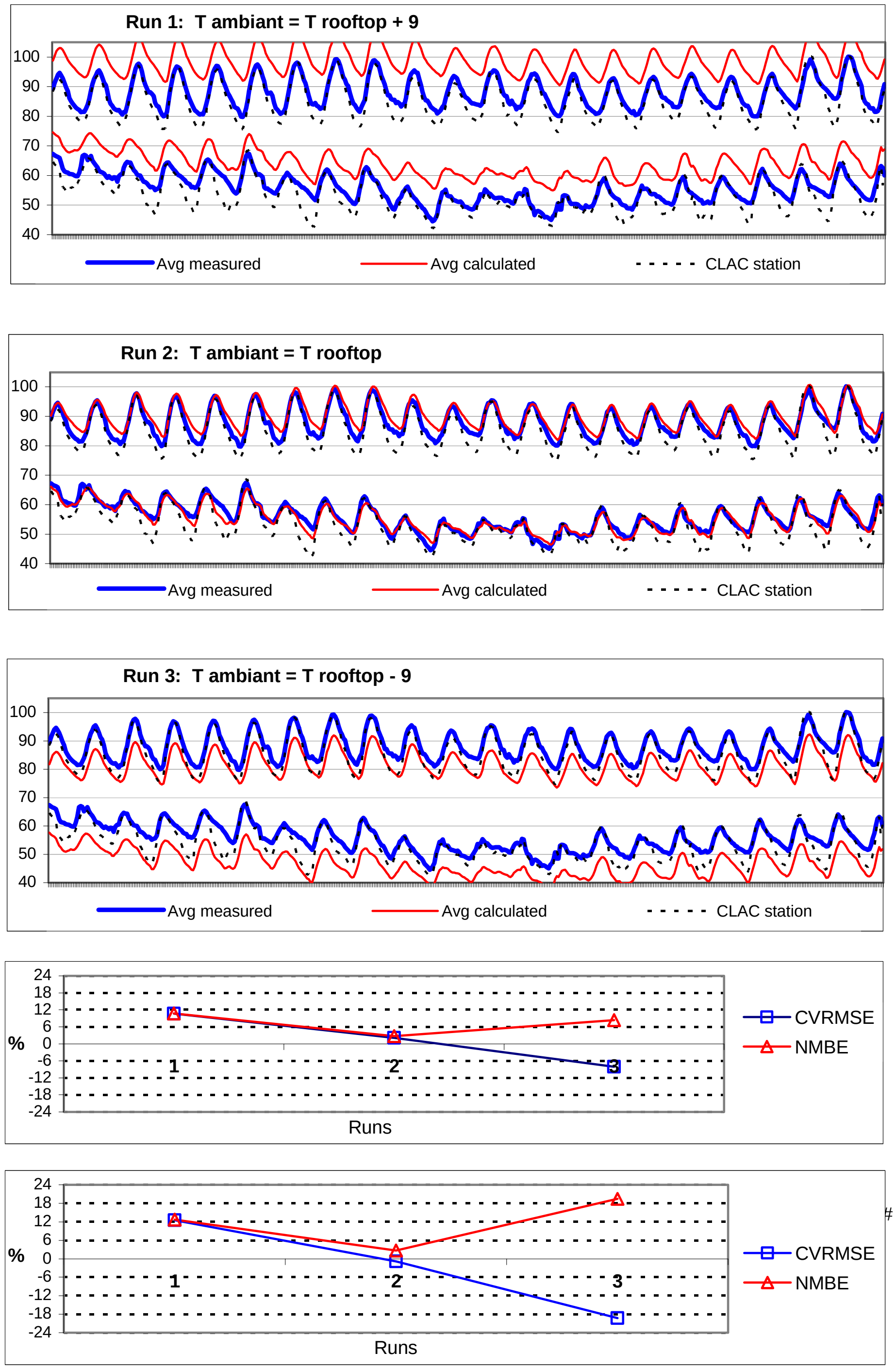


Figure 5.19c Sensitivity Runs for the Courtyard Microclimate FD Model while Varying the Cloud Cover (0, 50, & 100%), Showing Close-up of Four Winter Days.



		CVRMSE	NMBE
Run 1	AUG	10.6	10.7
	JAN	12.6	12.7
Run 2	AUG	2.2	2.7
	JAN	-0.9	2.7
Run 3	AUG	-8.1	8.3
	JAN	-19.3	19.5

AUG

JAN

Run 1 T ambiant = T rooftop - 9
Run 2 T ambiant = T rooftop (As is)
Run 3 T ambiant = T rooftop + 9

Figure 5.20a Sensitivity Runs for the Courtyard Microclimate FD Model with Ambient Air ± 9°F of its Real Value.

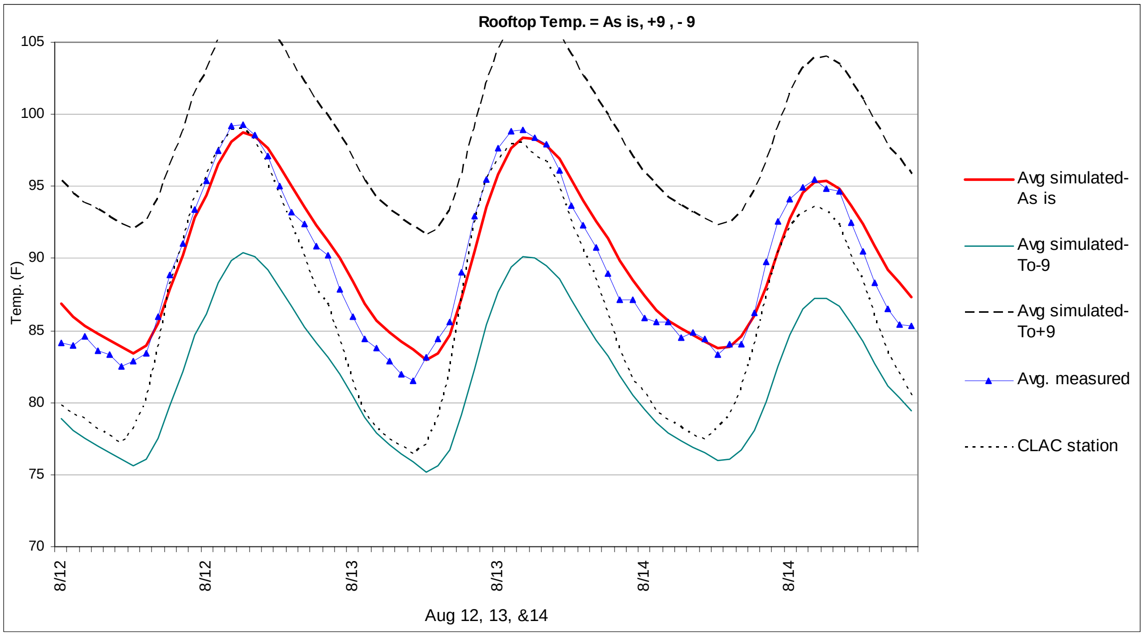


Figure 5.20b Sensitivity Runs for the Courtyard Microclimate FD Model with Ambient Air ± 9°F of Its Real Value, Showing Close-up of Three Summer Days.

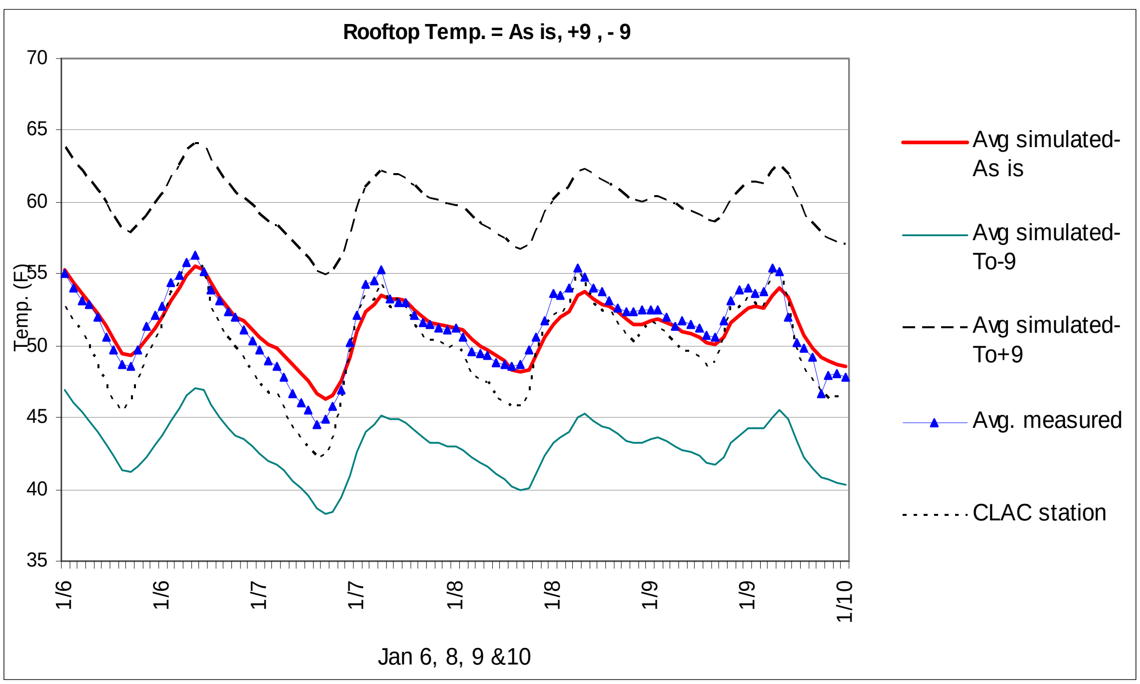


Figure 5.20c Sensitivity Runs for the Courtyard Microclimate FD Model with Ambient air ± 9°F of Its Real Value, Showing Close-up of Four Winter Days.

Figure 5.21 shows the resulting temperatures from five consecutive runs during the winter monitoring period while varying the thermal mass (0.25, 0.5, 1, 1.5, & 2 times the original house mass). The Figure shows a convergence deficiency that is shown with the dashed line and can be seen as the shaded area under the difference curve. This deficiency grows worse with increasing thermal mass. It is caused by the simulation beginning on the first day of the year 1-1 and ending on 12-31, where as the monitored data began on 12-29 and ran through 1-19. The convergence problem is a step-change in the predicted versus measured temperature difference that gradually disappear over a number of days.

A close look at the summer monitored data would provide a good background for the simulations that will be processed in this section. Figure 5.22a presents a time series plot for the rooftop, courtyard microclimate, and the reception hall (interior space) temperatures recorded over a 21 days period in August. This plot shows the courtyard temperature falling between the rooftop and the reception hall, being cooler than the rooftop during the day and warmer than the rooftop during the night. The Figure shows that the temperature differences are not consistent throughout the monitoring period, yet a typical pattern is evident. Figure 5.22b presents a 24 hours temperature profiles for the 21 days of recorded temperatures from the rooftop, courtyard microclimate and reception hall along with the hourly average temperatures for each. This plot shows the typical temperature pattern for the rooftop, the courtyard and the reception hall. It may also be deducted from this figure that the thermal performance of the reception hall is not solely related to the courtyard temperature, as it is cooler than the courtyard during the day and warmer during the night. The only other factor that would contribute to the recorded thermal performance of the reception hall is the thermal mass within its walls and floor, and the ground temperature. It is worth noting that the case study house currently had its fountain buried under the pavement of the main courtyard and had the neighbor buildings that were attached to it removed, which would otherwise contribute the thermal performance of the house besides the thermal mass of the house. Thus, a number of DOE-2 simulations will be dedicated to investigate the effect of changing the

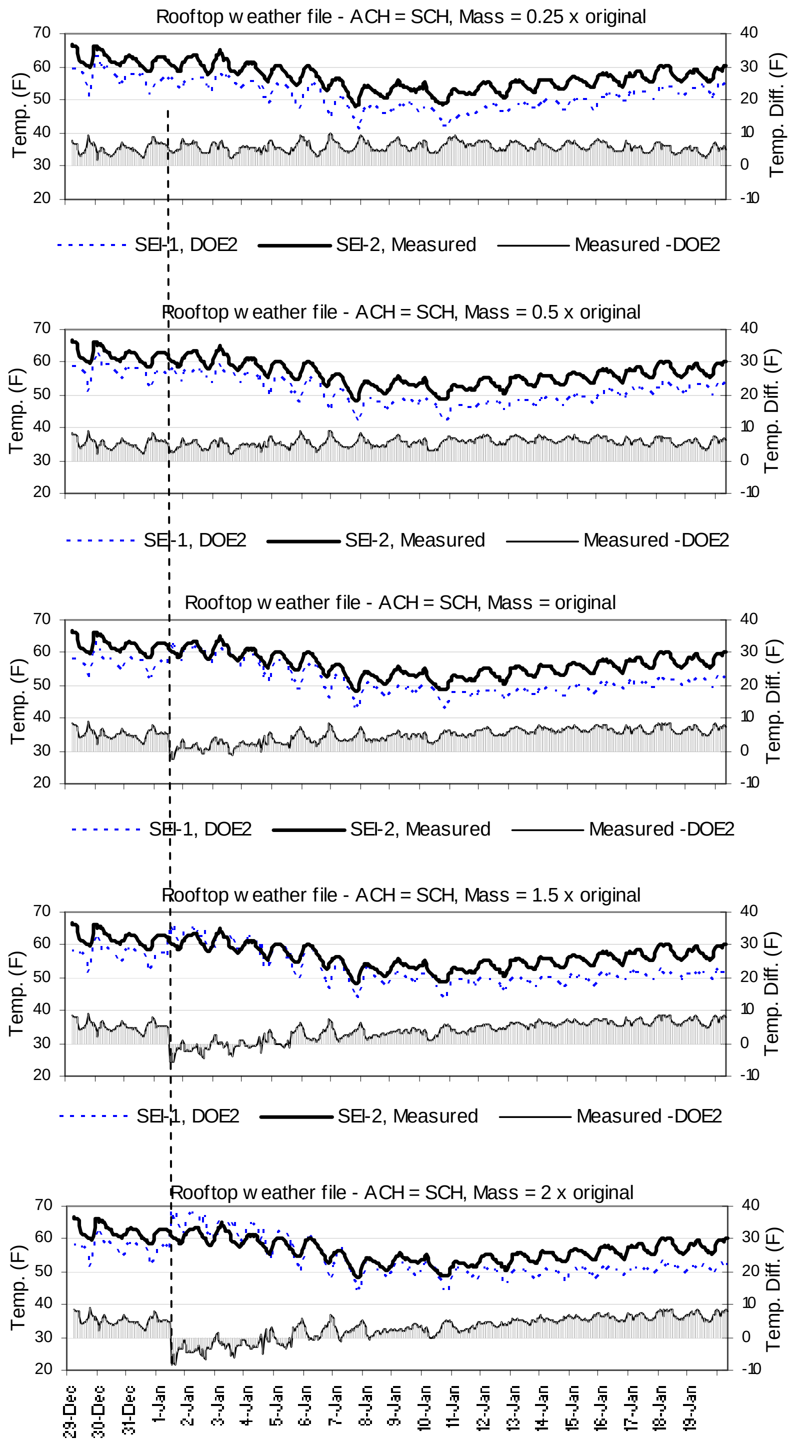


Figure 5.21 Results of Five DOE-2 Runs for the Abstract Courtyard House Model Comparing the Simulated with the Monitored Temperatures During the Winter Monitoring Period (Dec. 28 – Jan 18) While Varying the Thermal Mass (0.25, 0.5, 1, 1.5, & 2 times the original mass).

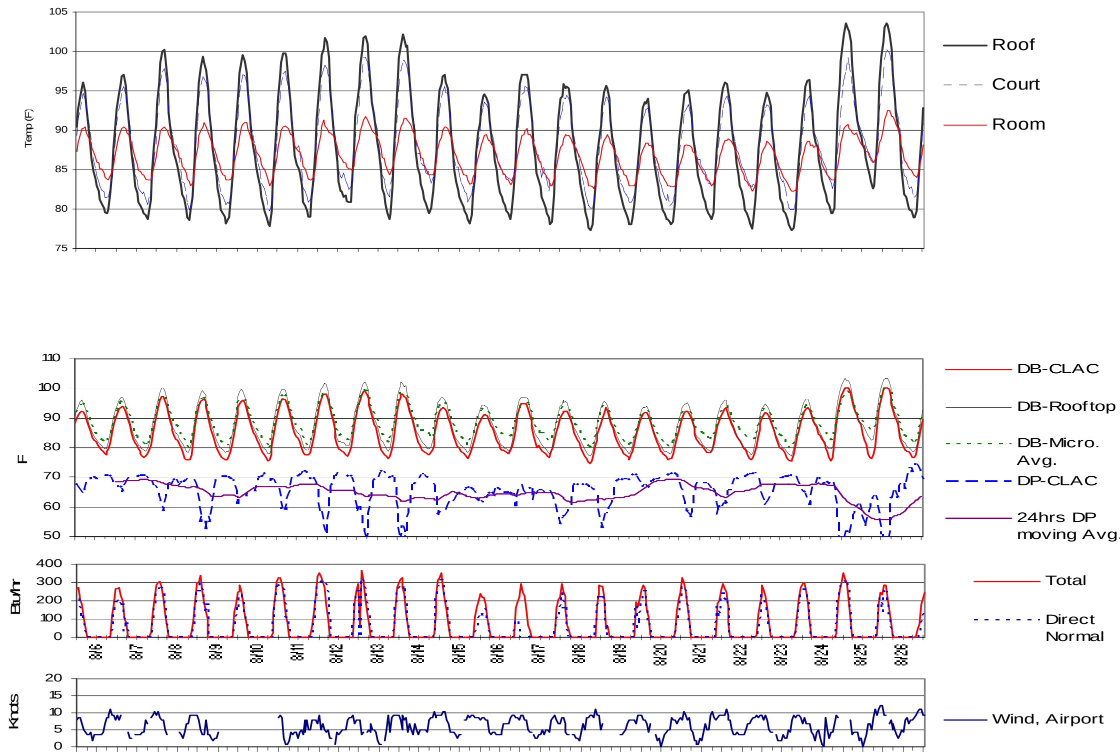


Figure 5.22a A Time Series Plot for the Rooftop, Courtyard Microclimate and the Reception Hall (interior space) Temperatures Recorded Over 21 Days Period in August.

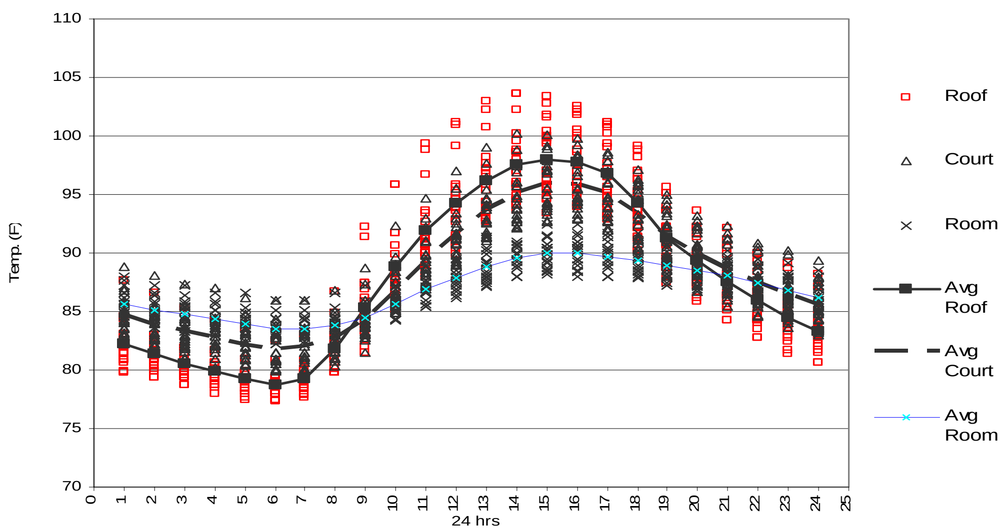


Figure 5.22b 24 Hours Temperature Profiles for the 21 Days of Recorded Data from the Rooftop, Courtyard, and Reception Hall along with the Hourly Average Temperatures for Each (August, 2001).

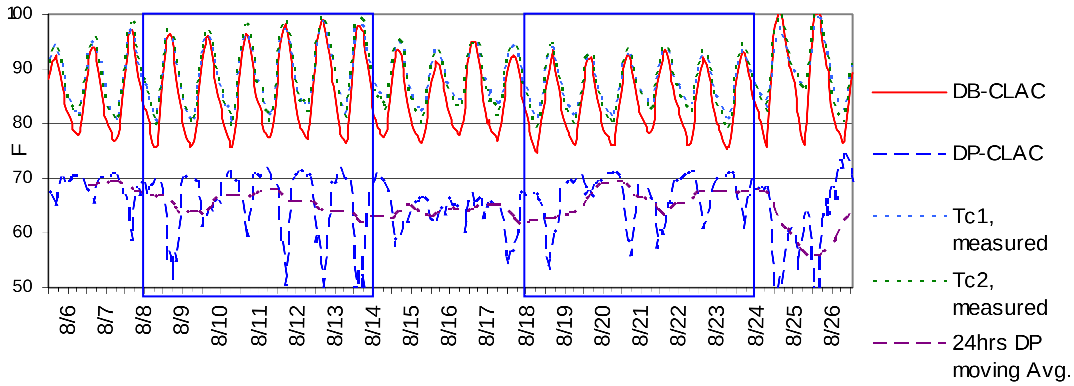
changing the thermal mass of the house.

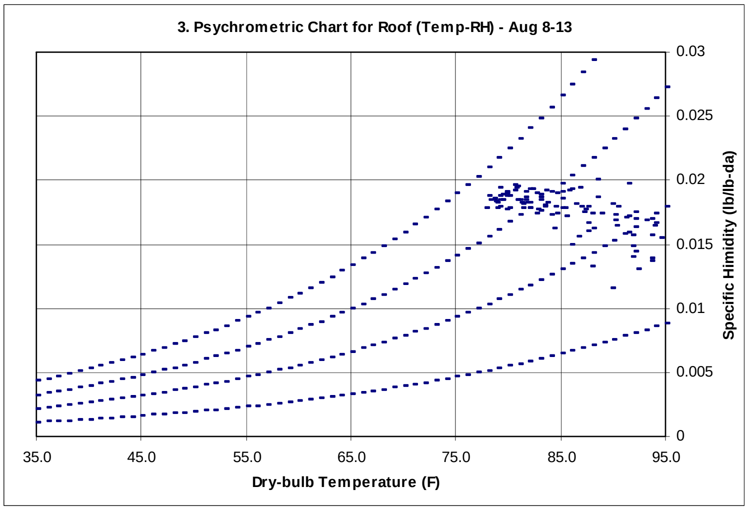
When the thermal mass of the original house was applied to the abstract model, the exterior envelope of the abstract house was modified to contain the majority of the thermal mass leaving small amounts of mass for the interior walls. This was due to the fact that that abstract model had a larger envelope area than that of the original house. Consequently the abstract model had smaller internal mass ratio when compared to the original house which had a large amount of thermal mass within the interior walls, specifically at the ground floor. As a result, two versions of the DOE-2 abstract house model were investigated having the same total amount of thermal mass: the first having an exterior envelope thickness similar to the original house while the internal thermal mass is smaller than the that of the original house, and the second had an exterior wall thickness limited to a maximum of 1.3 feet to allow more thermal mass for the interior walls. These versions of the abstract house model will be named versions 1 &2, referring to the 'envelope mass' and the 'internal mass' versions.

It was noted that during the 21 summer monitoring days (Aug. 5-26) an unexpected weather front moved through around August 15 and remained until around August 24. This weather front caused the air to be less humid. This was found to have a significant impact on the simulation results. Therefore, the analysis during these two periods will be referred to as the high and low-humidity periods.

Figure 5.23 shows two psychrometric plots for the rooftop summer weather data: the upper plot is for the five day period between August 5 and 13 representing the high-humidity period with higher enthalpy. The lower plot is for the five day period between August 18 and 23 representing the low-humidity period with lower enthalpy. The humidity change can be seen as a downward shift in the cluster of points from the upper plot to the lower plot.

Throughout this section the Figures for the DOE-2 simulation results includes at its lower section graphs for the ambient weather (DB, DP, solar) from the CLAC weather station, rooftop DB and courtyard microclimate temperatures, wind speed from the airport weather station, along with a curve for the 24 hrs DP moving average.





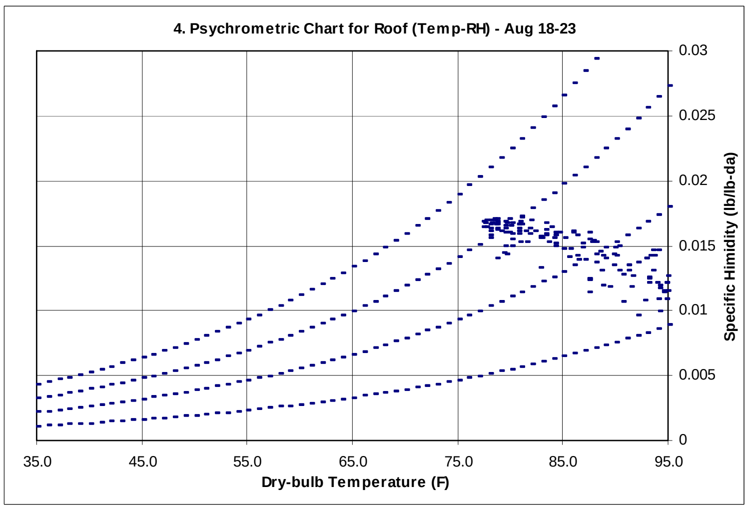


Figure 5.23 Two Psychrometric Plots for the Rooftop Summer Weather Data. The top Plot is for the Period between August 5 and 13. The Lower Plot is for the Period between August 18 and 23.

5.5.1 Courtyard House Base Case Simulation Calibration

The standard base case run used one ambient weather file (i.e., the IWEC file augmented with CLAC data during the monitoring periods). In this base case simulation of the abstract courtyard house, the DOE-2 program used the ambient weather file for both the courtyard as well as the exterior envelope of the house, thus ignoring the courtyard microclimate.

The temperature output from this run is presented in Figures 5.24a and 5.24b for both abstract house models version 1 and 2 along with calibration runs that were made with a number of ACH rates (1,5,10,15,20,25,30,35,&40). The results showed the calibration improved with increasing the ACH rate. Yet in the run with the lowest ACH rate (i.e., ACH= 1) the resulting maximum daily temperatures were the closest to the measured data, and in the run with the highest ACH rate (i.e., ACH= 40 for version 1 and ACH=30 for version 2) the resulting minimum daily temperatures matched well with the measured data. Therefore, an hourly ACH schedule was applied to the DOE-2 input file based on the analysis of the previous runs which considered a low ACH rate (i.e., 1) at the hour of the maximum measured daily temperature and a high ACH rate (i.e., 40 or 30) at the hour of the minimum measured daily temperature, while interpolating the ACH rates between these two hours around the day. Figure 5.25 shows a plot of the hourly ACH schedules.

The abstract courtyard house DOE-2 input files applying these ACH schedules were used for all subsequent runs. Each of the plots in Figures 5.24a and 5.24b include a temperature difference curve between the final simulation applying the ACH schedule against the measured temperatures. In the case of the version 1, ‘envelope thermal mass’, this curve shows that the simulated temperatures were less than the measured temperatures during most of the high humidity period, then it became higher than the measured temperatures throughout, except during the peak hours. In the case of the version 2 model, ‘internal thermal mass’, this curve shows that the simulated temperatures compares well with the measured temperatures during the night time, while the simulated temperatures were higher than the measured temperatures during the daytime.

It is worth noting that the reception hall at the ground floor where the indoor temperatures were recorded is between two courtyards (main and service courtyards). During the measurements periods repetitive airflows were observed (videotaped occurring every ~5 minutes) between both courtyards on opposite sides of the hall. It was estimated that these airflows would produce an ACH of about 10 ACH. In the other spaces of the house very small ACH were observed (i.e., less than 3ACH), except for the spaces at the roof level. Therefore, the ACH rates reaching 30 or 40 ACH applied to all spaces in the house were not realistic, considering that the house has most of its openings on the internal courtyards with very few openings on its exterior envelope. Also the ACH schedule profile contradicts the daily wind speed profile of the airport weather station as shown on Figures 5.25 and 5.26, which implies that the ACH schedule does not reflect a daily ambient airspeed profile. Therefore it appears that the applied ACH schedule is accounting for other factor(s) that are not adequately handled by the DOE-2 program. Additional work would be needed to resolve this non-intuitive ACH schedule.

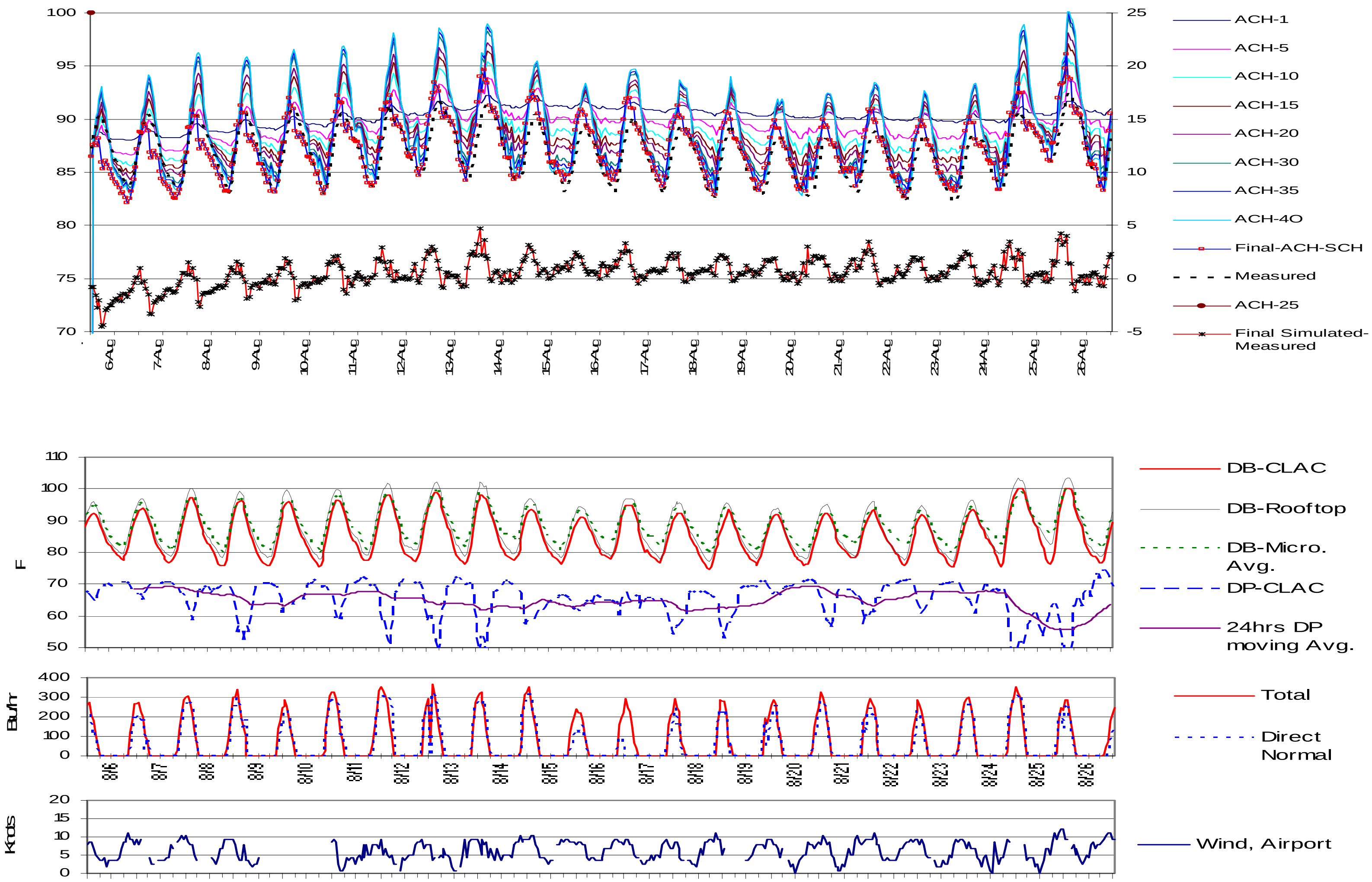


Figure 5.24a Calibration Runs for the DOE-2 Abstract House Model 'version 1' with Different ACH Rates (1,5,10,15,20,25,30,35,&40) While Using the Ambient Weather File, in Addition to a Final Run with a Varying ACH (according to the schedule in Figure 5.22).

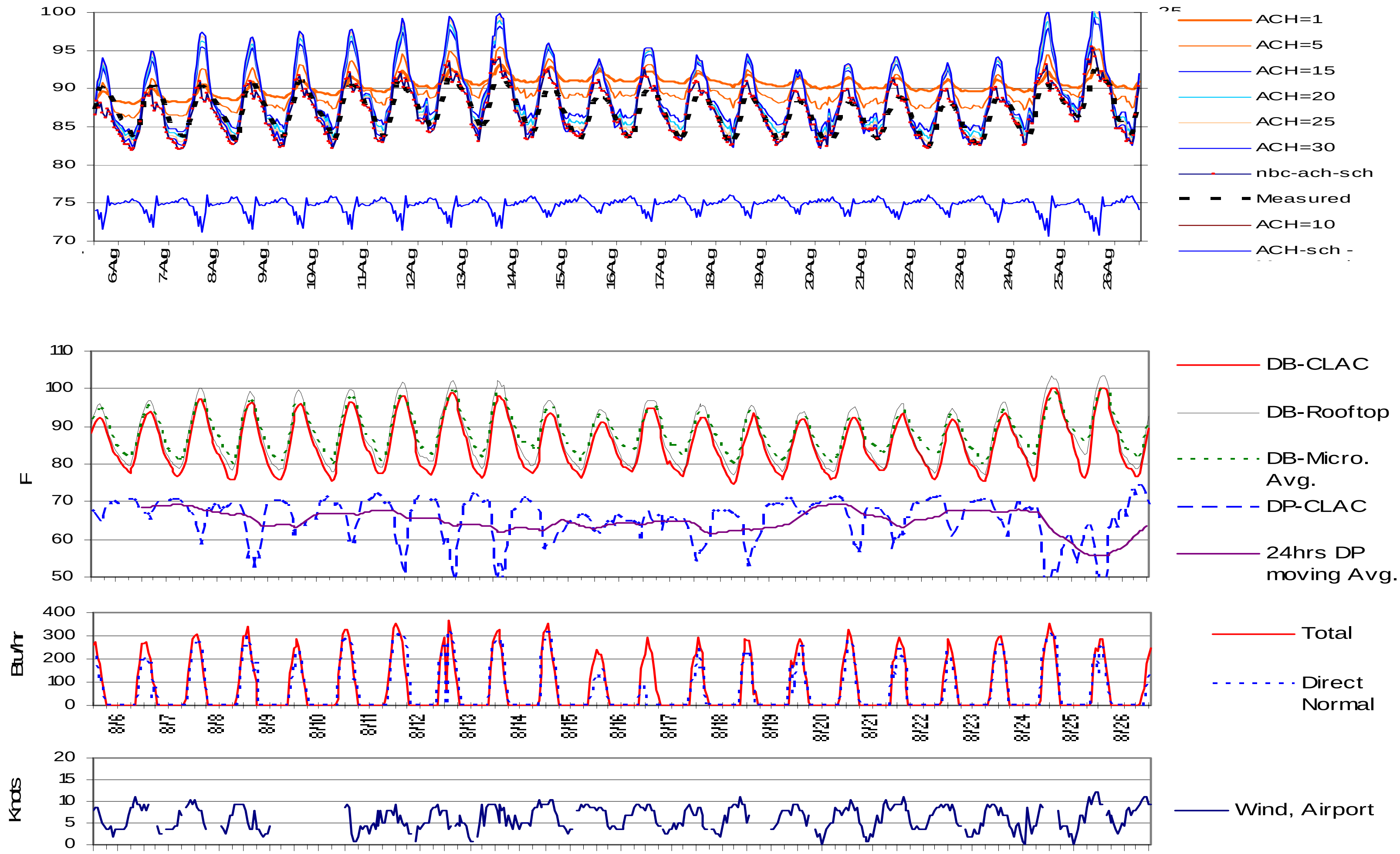


Figure 5.24b Calibration Runs for the DOE-2 Abstract House Model 'version 2'with Different ACH Rates (1,5,10,15,20,25,&30) While Using the Ambient Weather File, in Addition to a Final Run with a Varying ACH (according to the schedule in Figure 5.22).

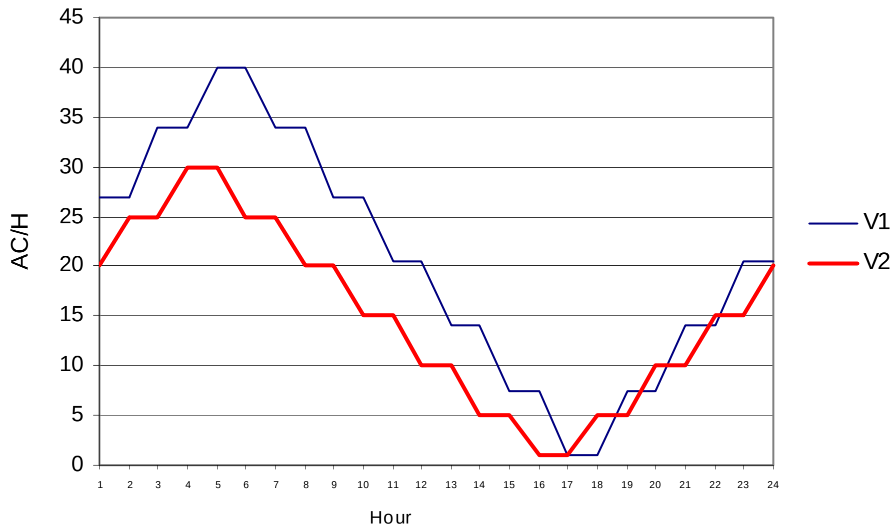


Figure 5.25 Hourly ACH Schedule Applied to the Abstract House Models Versions 1&2 Based on the Results of Calibration Runs for Different ACH Rates (1, 5, 10, 15, 20, 25, 30, 35, &40).

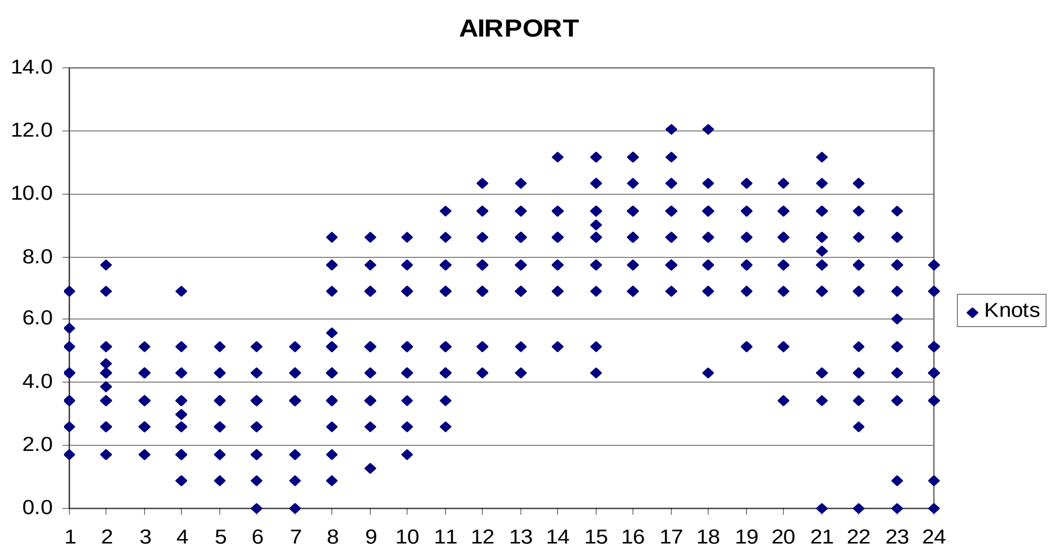


Figure 5.26 24 Hours Wind Speed Profile at the Airport Weather Station during the Summer Monitoring Period (August).

5.5.2 Courtyard House Base Case Simulation with Rooftop Weather File

In this analysis a site-related base case run was made that considered the ambient weather file (i.e., IWEC data) augmented with rooftop weather data for the summer and winter monitoring periods (21 days for each period), which affected the entire envelope of the house (i.e., the courtyard walls as well as the exterior building walls). Figure 5.27 shows the resulting space temperatures from these runs. The temperature difference curves showed that in both case the temperature difference curves were similar.

5.5.3 Courtyard House Simulation That Considers the Courtyard Microclimate Weather File

In the final set of runs**,** the house was split into two rings of zones: an inner ring of zones affected by the FD courtyard microclimate weather file and an outer ring of zones affected by an ambient weather file (i.e., IWEC augmented with rooftop)**.**

The abstract house model version 2 ‘internal thermal mass’ was used in this analysis. Figure 5.28 shows one year of hourly simulated courtyard microclimate weather that was applied to the inner ring of zones. The figure shows also a comparison with to the file of the ambient weather (i.e., the IWEC augmented with rooftop data during the monitoring periods) that was applied to the outer ring of zones. Two separate runs were made. The first run considered the ambient weather file with the outer ring of zones having its exterior envelope affected by it, while the adiabatic interior walls, having no thermal exchange, were used to separate this outer ring of zones from the inner ring of zones. The hourly temperature outputs for each zone of the outer ring from the first run were reduced to monthly average temperatures to be used in the second run.

In the second run these monthly average temperatures were used as indoor air-condition set-points for the outer ring zones, while having an unconditioned inner ring of zones (including the southeast wing inner zone space opening onto the courtyard at the ground floor representing the monitored reception hall) exposed to the courtyard microclimate.

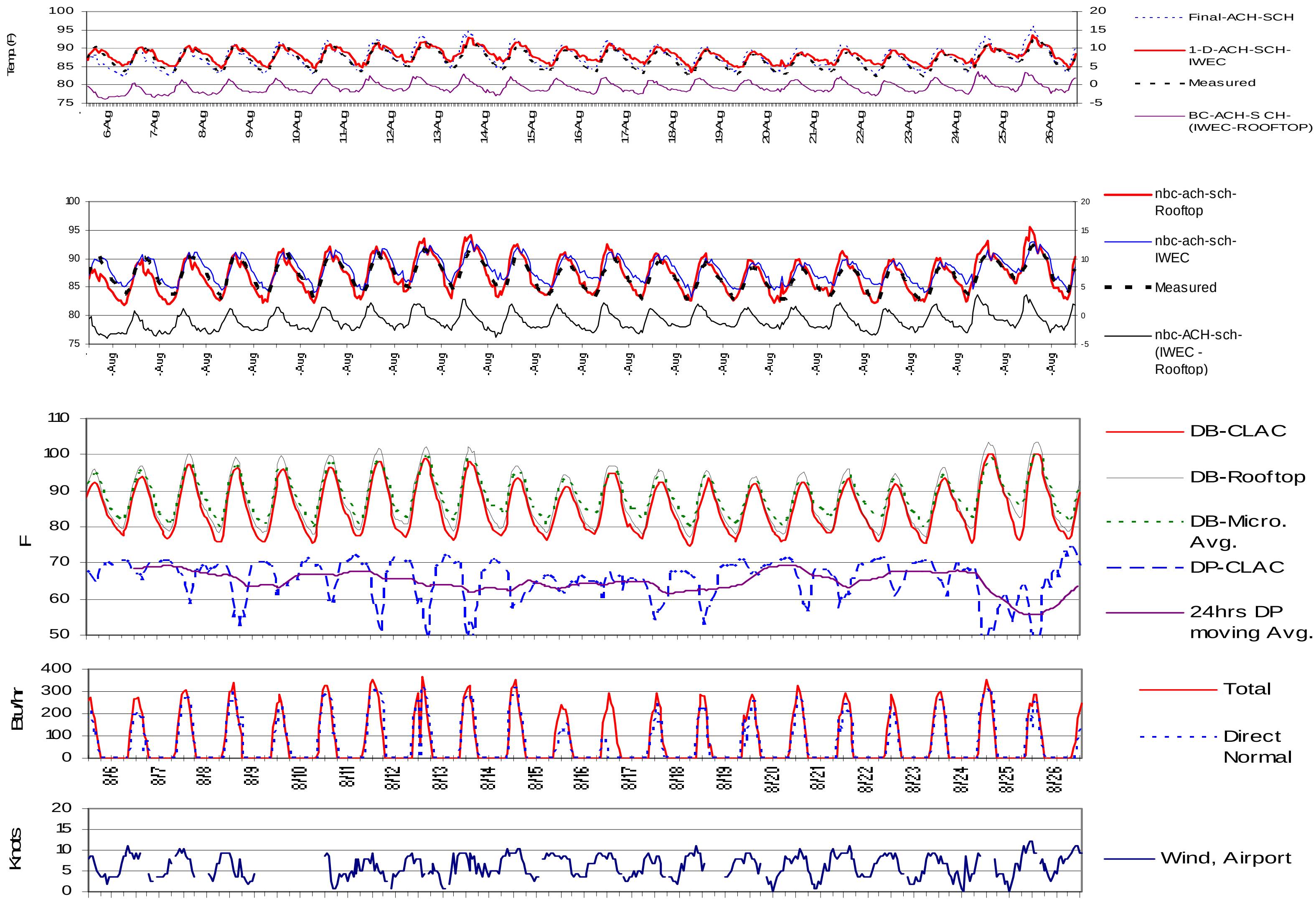


Figure 5.27 Comparison between Two Simulation Runs, each Applying a Different Weather File: IWEC with CLAC Data, & IWEC with Rooftop Data for the Abstract House Model with ΔT, the Upper Graph for the Abstract House Version 1 and the Lower for Version 2.

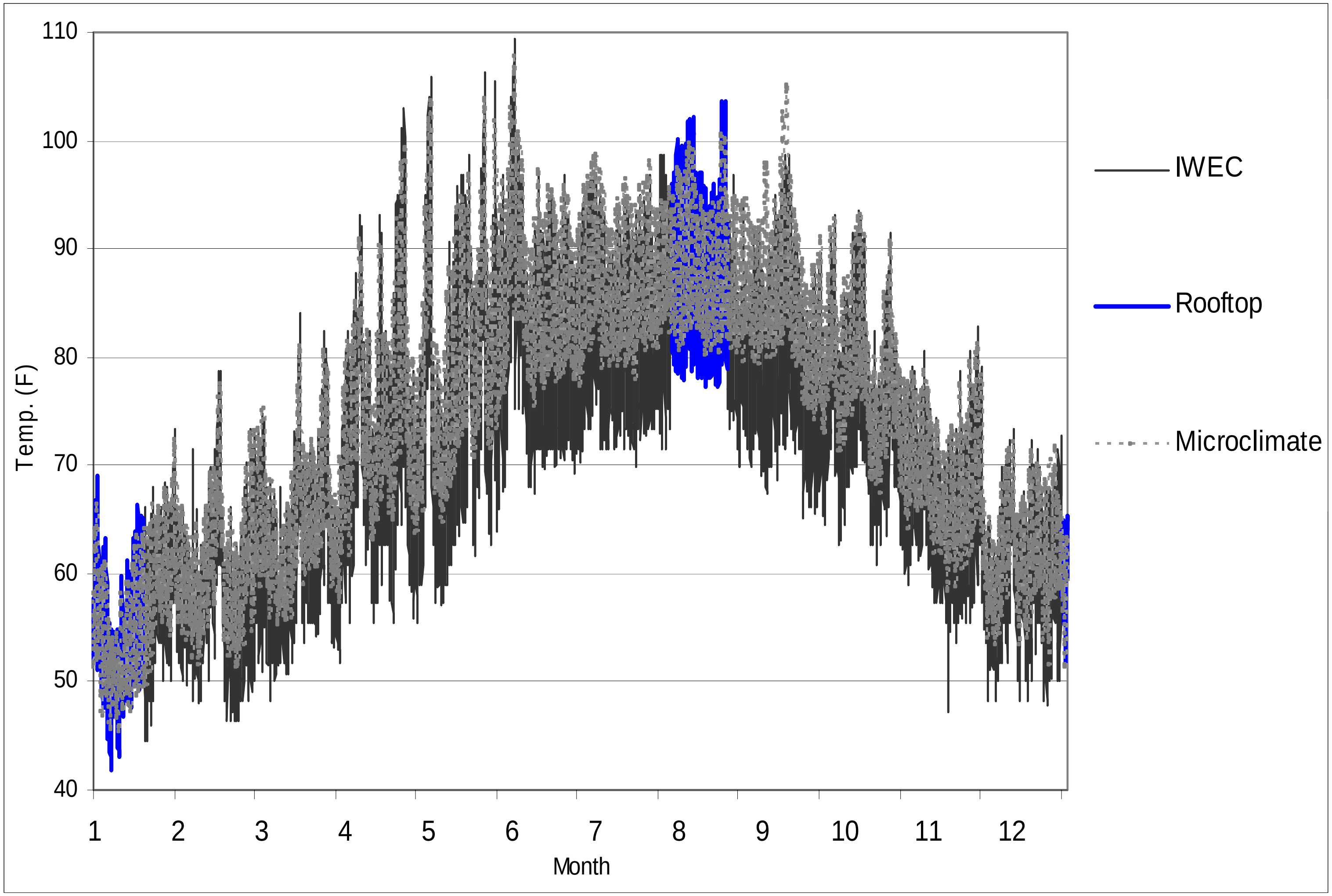


Figure 5.28 One Year of Hourly Simulated Courtyard Microclimate versus the IWEC Weather File Augmented with Rooftop Temperature Records During the Monitoring Periods.

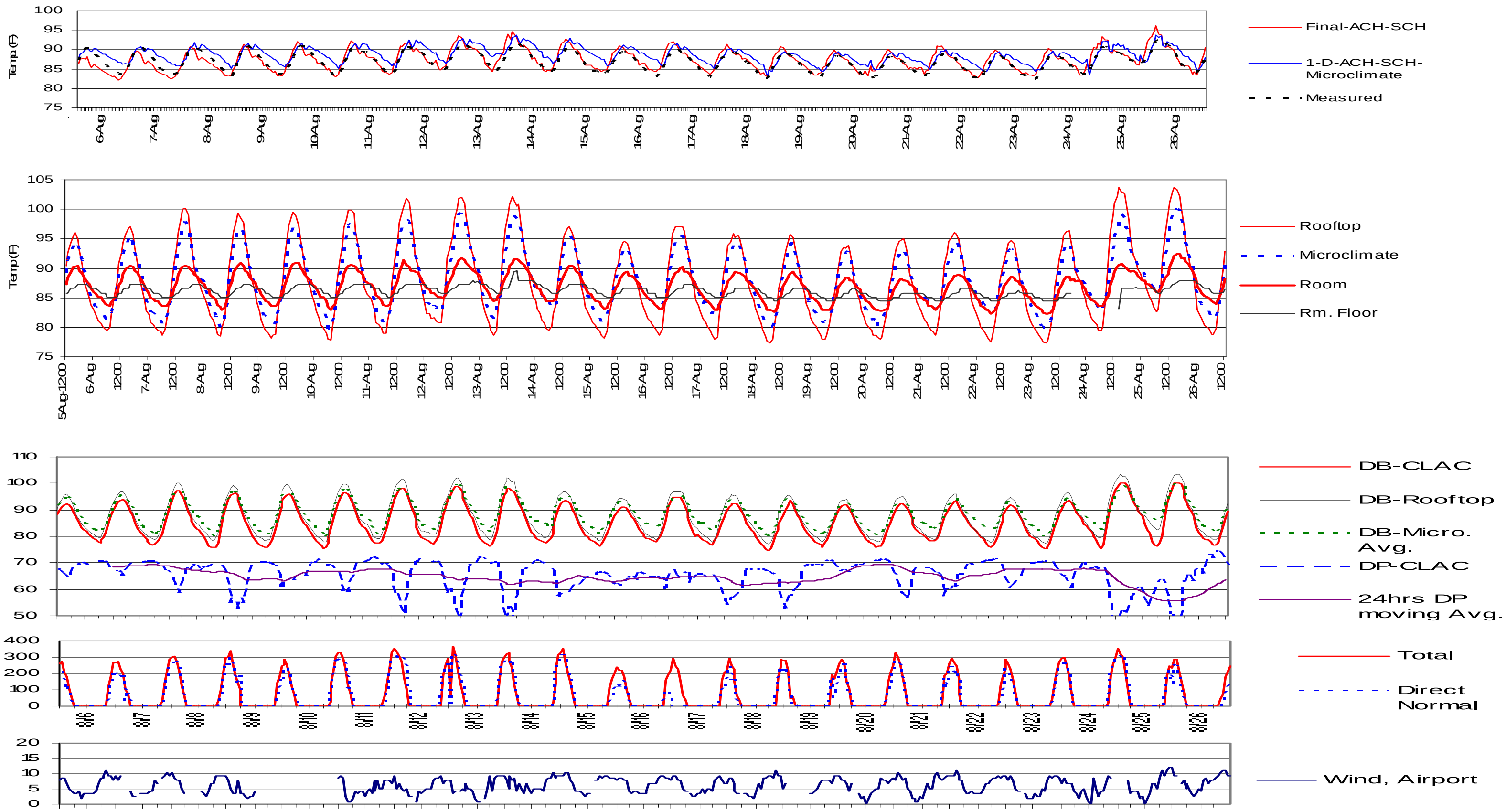


Figure 5.29 Comparison between Two Simulation Runs for the Abstract House Model Version 2, Each Applying a Different Weather File: Courtyard Microclimate (for inner house zones) with IWEC with Rooftop (for the outer house zones), and IWEC with Rooftop for the Whole House.

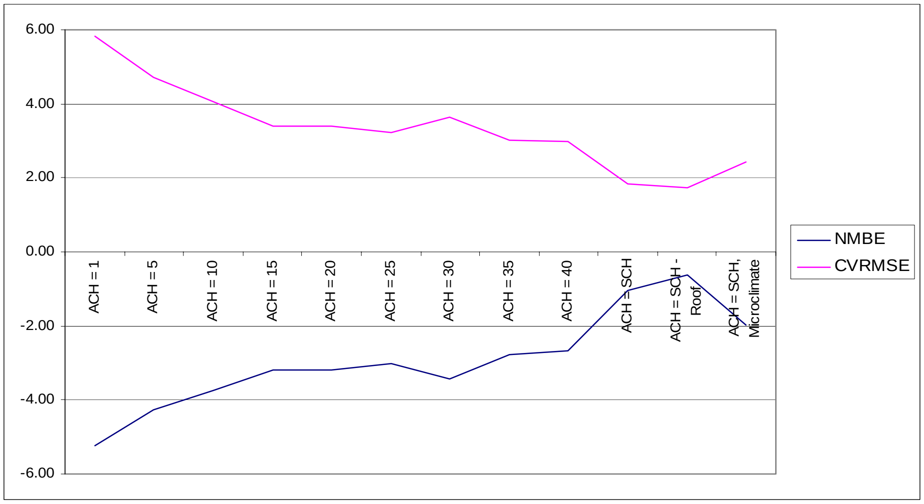


Figure 5.30 Calibration Indices Results for the Case Study House Simulation Runs (summer period). The First 9 Runs with ACH Rates (from 1 to 40), the 10th, 11th and 12th Runs Applied the ACH Schedule. The 11th Run Applied the Rooftop Weather Data (Combined with IWEC Data) and the 12th Run with the Courtyard Weather Data Applied to the House Inner Zones (While the Rooftop Weather Data Was Applied to the Outer Zones of the House).

Figure 5.29 shows the output temperatures for this run. Figure 5.29 also allows for a comparison between the two DOE-2 simulation runs for the case study abstract house each applying different weather files:

- IWEC augmented with rooftop data during the summer and winter monitoring periods,
- The courtyard microclimate applied to the inner ring of zones, while the outer ring of zones was exposed to the ambient weather file (i.e., IWEC augmented with the rooftop weather during the monitoring periods).

The results from the simulation run that considered the rooftop weather data matched closely with the measured data except during the morning time up to the peak hours where it was warmer. The results from the simulation run that considered the courtyard microclimate weather file for the inner ring of zones showed to be slightly cooler than the measured data during the morning, and slightly warmer during the afternoons and evenings with a time lag shift for the highest and lowest records.

In an attempt to interpret this, additional data were included in Figure 5.28 that shows the measured ground (i.e., Rm. Floor) and air temperatures of the room (i.e., Room), the courtyard microclimate (i.e., Microclimate) and the roof (i.e., Rooftop) temperatures. This new graph shows that the ground temperature was cooler than the room air temperature during the day and warmer during the night, contrary to the courtyard microclimate which was warmer during the day and cooler during the night. This suggests that the ground temperature contributes to the room air temperature. However the DOE-2 simulation uses a single average ground temperature per month which downplays the role of ground temperatures in the simulation. In addition, a single number for an estimated average cloud cover was applied to the weather file during the monitored periods which would affect the nocturnal radiation cooling for the building envelope.

The simulation with the rooftop weather file gave good simulation during the afternoons and nights, yet it showed higher temperatures during the morning hours up to the peak hour. On the other hand, the time lag occurring in the simulation that applied the courtyard microclimate weather file (while not showing in the one that applied the rooftop weather file) could be related to the fact that the courtyard microclimate have a time lag shift compared to the rooftop temperatures. It is worth noting here that in Figure 5.4 which compared the measured courtyard microclimate to both the rooftop and CLAC weather data, the courtyard microclimate showed to posses a time lag.

Figure 5.30 presents a plot of the calibration indices results for the previous DOE-2 case study abstract house model (version 1) simulation runs. The first 9 runs applied different ACH rates (from 1 to 40), while the 10th, 11th and 12th runs applied the ACH schedule. The 10th run applied the IWEC weather file augmented with CALC weather data, the 11th run applied the IWEC weather augmented with rooftop data, and the 12th run applied the courtyard microclimate weather data to the inner zones of the house, while the IWEC augmented with the rooftop weather data was applied to the outer zones of the house.

A comparison between the results of these three runs showed that the simulation that considered the whole house with the IWEC weather file augmented with rooftop weather data produced the best calibration results, yet it showed high temperatures around noon. One possible reason may be related to the rooftop having high temperatures around noon.

5.5.4 Courtyard House Base Case Simulation with Rooftop Weather Data While Considering Varying the Thermal Mass of the House

These simulations were made to investigate the impact of thermal mass on the indoor house temperatures that was discussed while reviewing the model courtyard housing projects in section 2.5. Table 5.2 presented a thermal mass inventory for the DOE-2 abstract model of the case study courtyard house. In general, the original house thermal mass had at its ground floor a 3 foot thick limestone wall, which was reduced to two feet at the first floor and to one foot at the second floor. To test this, variations in the mass in the simulation model were applied the house walls. The total amount of the original thermal mass of the house is approximately equal to a cube made of lime stone (density =140 lb/ft3) having the length of its sides equal to ~40 feet long.

A comparison between the two simulations having the same total mass, one with most of the mass on its exterior envelope and the other with its exterior envelope thickness limited to maximum width of 1.3 feet is presented in Figure 5.31a. The comparison between both simulations shows that the simulation having most of the house thermal mass on the exterior envelope had cooler temperatures during the nights and warmer temperatures during the afternoons.

When variations in the thickness for the abstract house model were applied in the DOE-2 software it returned an error when the thickness exceeded ~3.75 ft, this

Table 5.2 Thermal Mass Inventory for the DOE-2 Abstract Model of the Case Study Courtyard House.

		Variables	House wing SW	SE	NE	NW	Total
		Floor area (ft2)	545	1486	1176	595	3802
		Volume (1st floor)	7726	21093	16689	8437	53946
		Volume (2nd floor)	11680	31885	25228	12754	81546
		Volume (3rd floor)		24527	19406		43933
		Volume (3 floors)	19406	77505	61323	21191	179426
Floor	**1st floor** (height=14.19)	Mass(Lb.)	830204	1750019	875973	775638	4231834
		Density (lb/ft2)	1525	1177	745	1304	
		Density (lb/ft3)	107	83	52	92	
	2nd floor (height=21.45)	Mass	547036	1159321	903283	586858	3196497
		Density (lb/ft2)	1005	780	768	987	
		Density (lb/ft3)	71	55	54	70	
	3rd floor (height=16.5)	Mass		743108	681735		1424843
		Density (lb/ft2)		500	580		
		Density (lb/ft3)		30	35		
	All house	Mass	1377239	3652448	2460991	1362496	8,853,174
		Avg. Density (lb/ft2)	843	819	697	764	
		Avg. Density (lb/ft3)	59	56	47	54	

Notes:

1- A representation of the density in the form of lb/ft3 was produced since the floor heights of the house were unlike the conventional.

2- For the case-stuy DOE-2 abstract mode, the mass for each zone in each floor was compared to the original house and calculations showed that the mass in the abstract model varied between 95% to 110% of the original house.

3- The total house mass of the house in the abstract model was 91% of the original house mass.

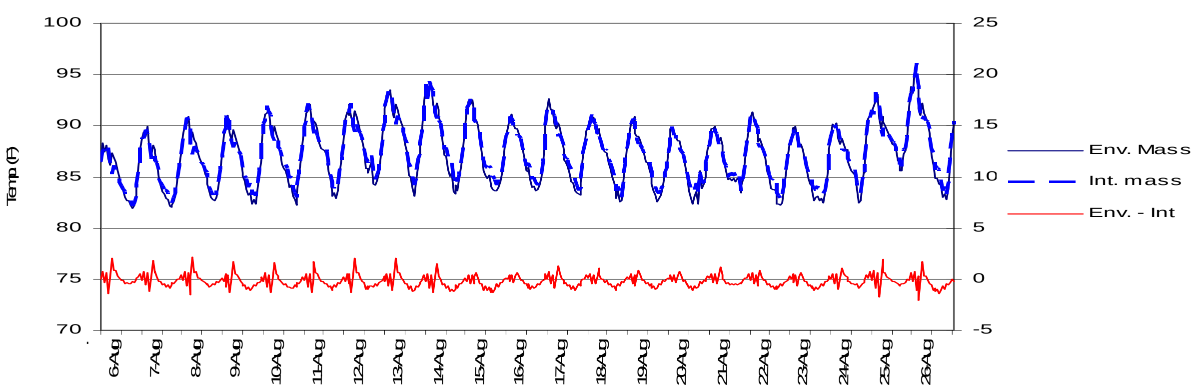


Figure 5.31a Abstract Model Space Temperatures Resulting from Applying Two Thermal Mass Variations: One with Most of the Thermal Mass on the External House Envelope and the Other While Limiting the Envelope Thickness to 1.3 ft.

hampered applying variations to the wall thickness over 1.25 times its original thickness. Thus variations in the house thermal mass that exceed 1.25 times were obtained from the second version by applying variations to wall density rather than to wall thickness. The second version was used in runs while varying the density 0.25, 0.5, 1, 1.5, & 2 times the original density.

Figure 5.31b shows the resulting interior space temperature from two sets of DOE-2 runs while varying the total thermal mass: the first that had similar thickness of walls to the original house (with most of the house mass on the exterior envelope of the abstract model) applied 3 variations to the thickness of the walls (0.25, 0.5, & 1.25), and the second that had the exterior envelope thickness limited to 1.3 ft. applied variations to the density of the walls (0.25, 0.5, 1.5, & 2) .

Figure 5.31b also includes ΔT curves showing the difference in the resulting space temperature between applying the original total mass and 0.25 of the original thermal mass for each of the abstract model versions. During the high-humidity period, the curve shows a temperature difference changing during the day with the resulting simulation temperatures of the 0.25 thermal mass higher than that for the run of the original thermal mass with a peak during the daytime (reaching a maximum of 3.5 F) and diminish towards the nighttime. During the low-humidity period the trend is reversed where the simulation temperatures of the 0.25 thermal mass are lower than that of the original thermal mass while the difference diminishes during the daytime and profound during the nighttime.

Also the graph include a second comparison curve showing the difference in resulting space temperature between a simulation that applied the original thermal mass and another that doubled the original thermal mass in density. During the high-humidity period, a temperature difference change occurred during the day with the simulation temperatures of the 0.25 thermal mass being higher than that for the run with the original thermal mass having its peak during daytime (reaching a maximum of 2 F), while the difference diminishes during the nighttime. During the low-humidity period this trend changes where the simulated temperatures for the original thermal mass run and the run with the doubled thermal mass are almost equal.

Comparing both temperature difference curves, it would be seen that during the high-humidity period the simulated temperatures for the run with low thermal mass (0.25 of the original mass) showed to be higher during the daytime than the run with the original thermal mass while being similar during the nighttime. During the low-humidity period the pattern changes as the low thermal mass run temperatures showed to be lower during the nighttime than the run with the original thermal mass while being similar during the daytime. For the simulation runs with double thermal mass, the temperature differences were less in amplitude during the high-humidity period and this difference diminished during the low-humidity period.

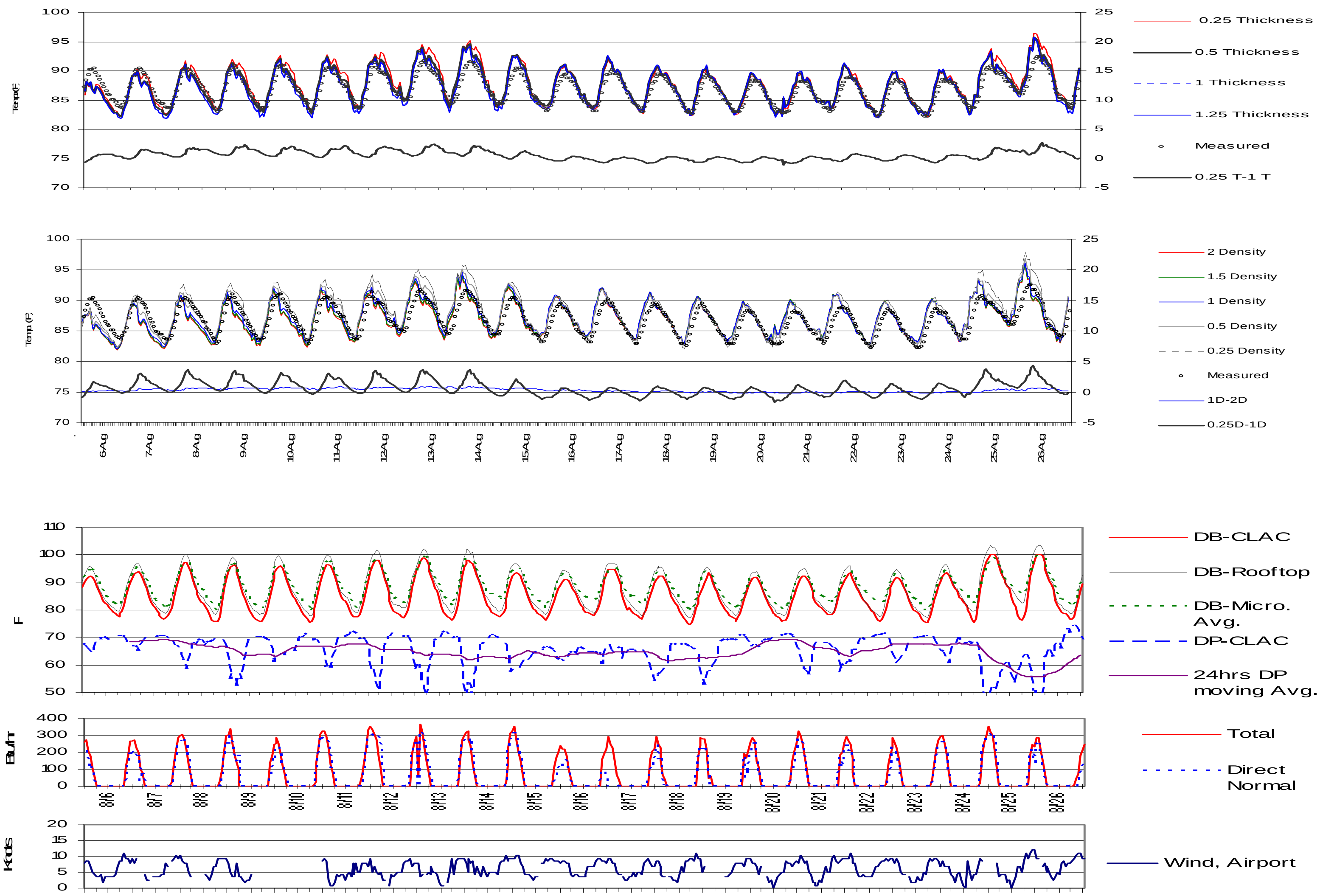


Figure 5.31b Case Study House Space Temperatures Resulting from Varying the Thermal Mass of the DOE-2 Abstract House Model: The Original Envelope Thickness (0.25, 0.5, & 1) and Density (0.25, 0.5, 1, 1.5, & 2).

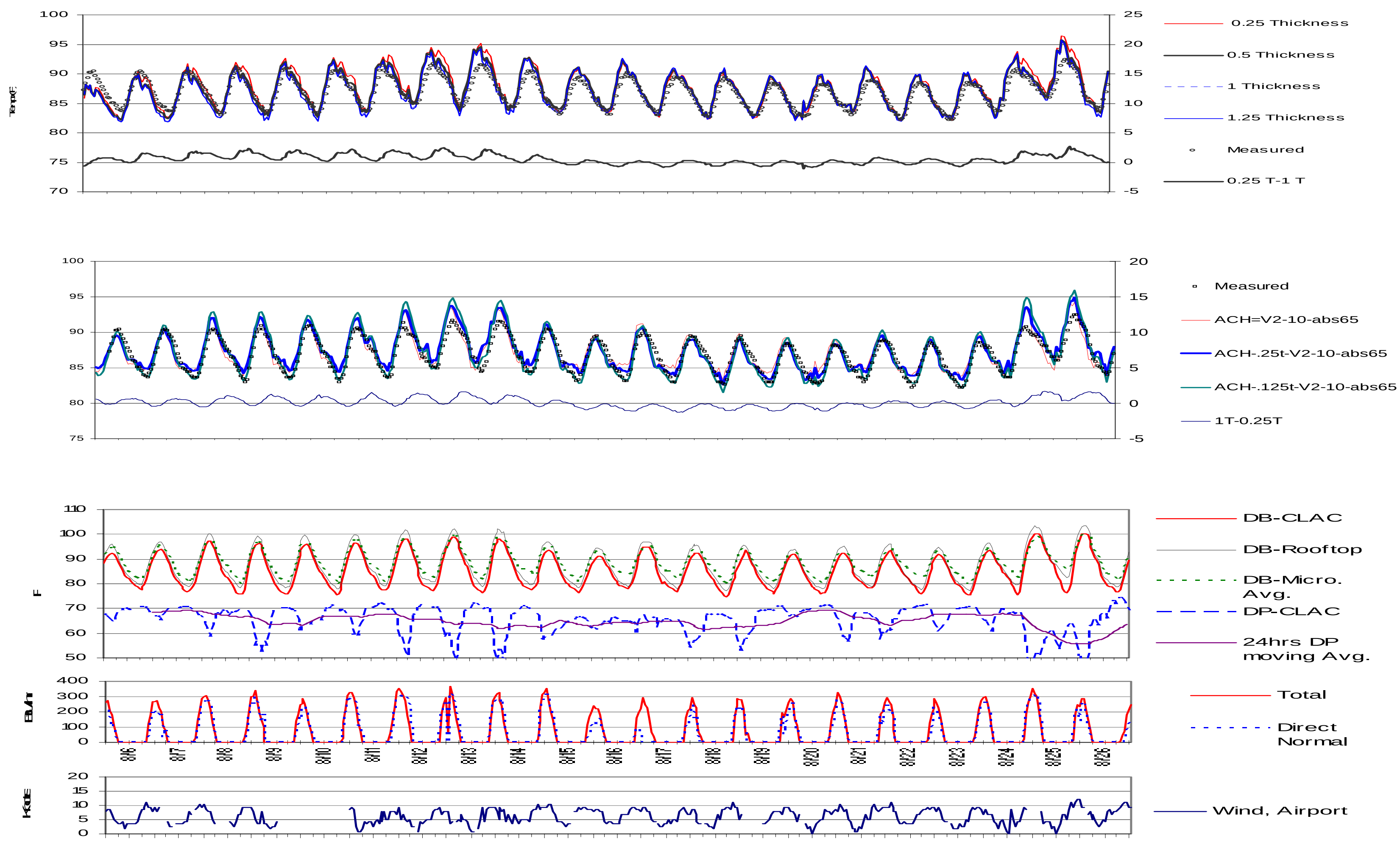
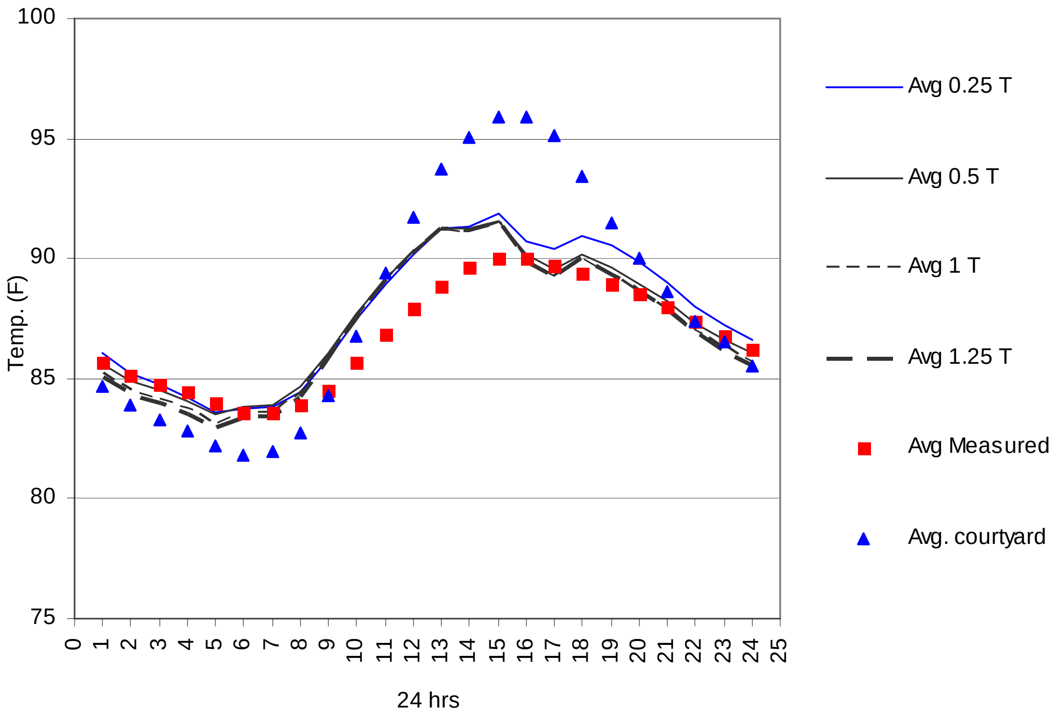


Figure 5.31c Abstract House Space Temperatures Resulting from Varying the Thermal Mass of the DOE-2 of the Original Envelope Thickness (0.25, 0.5, & 1) . The Upper Set of Runs Applied Hourly ACH Rates (between 1 and 30) and the Lower Set of Simulations Had Normal Values of Constant ACH Rates (2&10).

Figure 5.32 presents a 24 hour temperature profile plots showing variations in thermal mass. The upper plot varies the wall thickness, and the lower plot varies the wall density. During the morning hours all runs produced similar results, while during the peak hour, the afternoon, and night the results varied. During the afternoon hours the models that tested the thermal mass density produced different output temperatures (~2 to 3 F) among the applied treatments, compared to very similar simulated temperatures in the case of models that tested the wall thickness .

The impact of varying the thermal mass was expected to have a greater reflect on the simulated temperatures. To check whether this simulation deficiency may be resulting from the application of an hourly infiltration schedule with high rates reaching 30 ACH, a set of simulation runs were applied with the same variations in the wall thickness. These simulations were applied to the abstract house model except that it had normal ACH rates (2 & 10) around the house (i.e. uncalibrated model with temperatures ~3 to 5 F warmer than the measured records). The temperature differences among these set of simulations were found to be similar to that for the previous model that applied hourly air change schedule of high values. This confirms that in the initial set of runs the output was related to the building envelope performance rather than the high air change rates. Figure 5.31c presents the output from these runs.



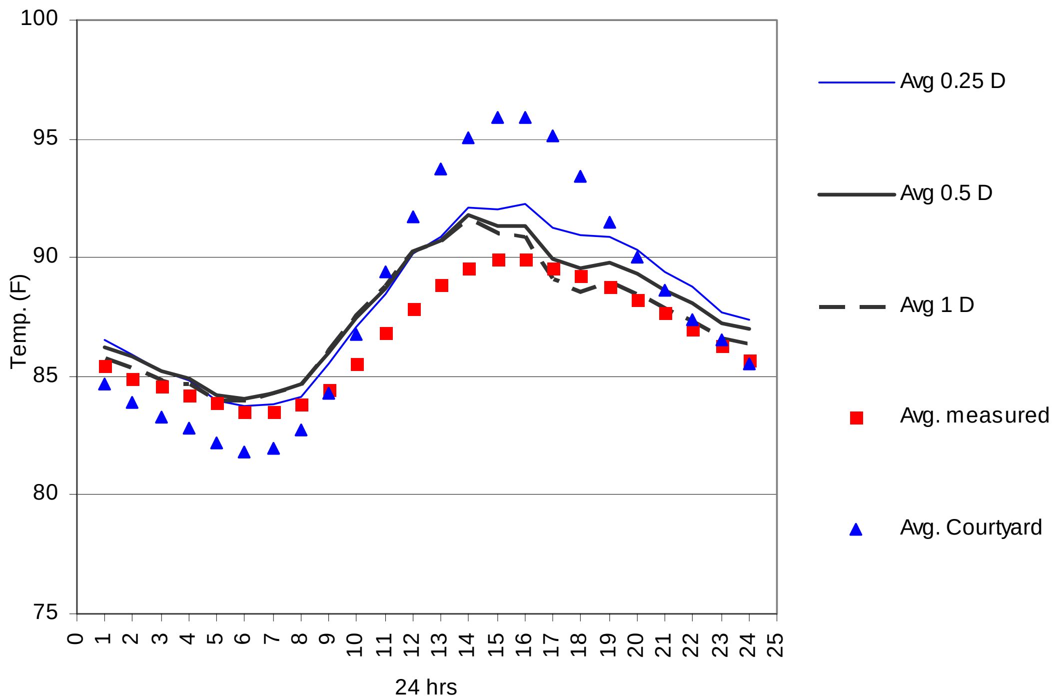


Figure 5.32 24 hrs Temperature Profile Plots Showing Variations in Thermal Mass. Upper Plot Varies Wall Thickness. Lower Plot Varies Wall Density.

5.6 Summary of Results

In this chapter the Cairo weather data, the thermal monitoring measurements of the case study house, the courtyard microclimate FD thermal network model simulation results, and the case study house DOE-2 model with and without considering the courtyard microclimate weather file were presented and analyzed. The analysis of the Cairo weather data from the CLAC and airport weather stations, along with the rooftop data showed the impact of the local environment on the measured weather data. It was found that using a weather file other than the one within the locality of the case study house would diminish the simulated microclimatic impact of the case study courtyard. The results from the onsite survey of the case study courtyard house provided useful information about its physical condition and operational schedules. The measurement results provided the data for the comfort analysis and the simulations calibrations. The courtyard microclimate FD model was calibrated while testing six different thermal mass values and six different ACH rates. The best fit was found with the actual thermal mass of the house and an ACH rate equal to 35 with an NMBE for summer ~1.5%, and for winter ~3.5%.

The successfully calibrated courtyard microclimate FD model was then used in running sensitivities for the courtyard FD thermal network model. Among the six sensitivity runs the ambient air temperature was found to be significantly sensitive, supporting the use of the rooftop temperature data, with NMBE & CV(RMSE) values that confirms the accuracy of the FD courtyard model in predicting the microclimate. Yet it is worth noting that the sensitivity runs that investigated the effect of a range of ACH indices showed an insignificant impact on the resulting courtyard microclimate temperatures. It also showed the highest changes between the NMBE & CV(RMSE) results (~4%), which may suggest further investigation in future studies.

Next, the output results from the calibrated FD courtyard model were then used in the weather file for the DOE-2 case study house calibration simulations. The first set of runs was made while considering the whole house affected by the IWEC weather file. This set of runs tested the impact of varying the ACH infiltration rates. An hourly ACH schedule was then applied to the DOE-2 input file based on the analysis of the previous runs which considered ACH rates range varying between 1 and 40 around the day that produced the best calibration.

Then the case study house abstract DOE-2 model with this ACH schedule was tested with an IWEC weather file supplemented with rooftop weather data during the summer and winter monitoring periods (21 days in each). This result showed a calibration improvement over the previous runs applying the IWEC weather file augmented with CLAC weather data during the monitoring periods. For the final set of runs**,** the house was split into two sets of zones: an inner ring of zones affected by the FD courtyard microclimate weather file and an outer ring of zones affected by an ambient weather file (i.e., IWEC augmented with rooftop)**.** Two separate runs were made: the first run considers the ambient weather file with the outer ring of zones having its exterior envelope and outer zones affected by it, while adiabatic interior walls having no thermal exchange were used to separate it from the inner ring of zones. The output hourly temperatures for each zone of the outer ring from the first run were reduced to monthly average temperatures that were used as indoor set-points for air-conditioned outer zones adjacent to the inner ring of zones in the second run. In this second run the courtyard's microclimate weather file was applied to the unconditioned internal ring of zones having its exterior envelope affected by it.

A comparison between the results of these two runs showed that the simulation that considered the whole house with the IWEC weather file augmented with rooftop weather data produced the best calibration results, yet it showed high temperatures around noon. This may be related to the high temperatures from the rooftop file.

Two unexpected findings regarding the DOE-2 program showed up during processing the DOE-2 simulations. The first was a convergence deficiency that showed on the first day of January when simulating the case study house. This was investigated further by varying the mass of the house (0.25, 0.5, 1, 1.5, & 2 times of the original mass). It was found that this deficiency becomes visible at thermal mass levels at or above the actual levels, which suggests that the program convergence settings need to be reset to absorb the effect of heavy thermal mass. Also a significant change was noticed in the simulated temperatures between two similar weather periods during the summer, one having an enthalpy that is higher than the other. Investigating the impact of the simulation of neighbor buildings attached to the exterior envelope of the house was not tested.

CHAPTER VI
SUMMARY, CONCLUSIONS, AND FUTURE RECOMMENDATIONS

6.1 Summary of Methodology

A methodology was developed for simulating a courtyard house. The goal was to obtain a simplified simulation model that accurately represents a courtyard house to be used in running sensitivity studies. To achieve this goal a survey, measurements, a finite difference FD thermal network for simulating courtyard microclimates, and a simulation model for the house in DOE-2 were designed, and utilized.

A survey of traditional courtyard houses in Cairo, Egypt was performed and a case study house was selected. The purpose of the survey was to select a house having the features of traditional courtyard houses. Field measurements for the courtyard air and floor temperatures, indoor spaces, and rooftop thermal conditions took place in the summer of 2001 and winter of 2002. Weather data was collected from a local weather station as well as the airport weather station. Building information was also collected, which is presented in Appendix C.

A finite difference thermal network for predicting the courtyard microclimate was programmed and calibrated to measured data. The program showed high levels of agreement with the measured data (i.e., NMBE< 2%). The microclimate weather data produced from the FD model was then packed as a weather file and used with the DOE-2 simulation. In the DOE-2 simulation the courtyard house was split into two rings of zones: an inner ring affected by the courtyard microclimate, and an outer ring of zones affected by the ambient weather. Calibration to measured data was then applied to the split DOE-2 simulation.

6.2 Summary of Results

A Finite Difference (FD) thermal network was created for simulating the case study courtyard microclimate. The model showed validity as it calibrated well against field data from the case study courtyard house for both summer and winter records (21 days periods in August, 2001, and in December 2001- January 2002).

This model allowed running parametric sensitivity studies on the courtyard thermal simulation factors. Parametric analyses were performed for a number of variables: air change rates, thermal mass, solar absorption, wall and floor emissivity, ground temperature, cloud cover, and ambient air temperature. The results of the parametric analysis showed that the model was sensitive to variations in the air change rates (ACH), solar absorptivity, and ambient air (rooftop) temperatures, and less sensitive to the emissivity of the courtyard envelop, mass of the building, cloud cover and ground temperature.

The calibrated courtyard microclimate model was then used in combination with thermal simulation software (DOE-2) to predict the thermal performance of the case study courtyard house, which was also validated with measured field data. Specifically, the courtyard FD microclimate simulation model was used to produce an annual hourly courtyard microclimate weather file that was applied in the DOE-2 software to affect the ring of the inner zones around the courtyard of the case study house. The simulated temperatures of an interior zone from the DOE-2 abstract model of the case study courtyard house were compared to measured temperatures (for the Reception hall overlooking the main courtyard at the ground floor). Unfortunately, the DOE-2 model did not perform as well as expected in simulating the natural energy for the case study courtyard house. To improve the simulation, an unrealistic air-change schedule was applied to calibrate the model, which improved the model. The simulation of the underground portions of the exterior walls did not work. Also, the simulations that considered variations in increasing the thermal mass showed a convergence deficiency on the first few days of the beginning of the simulation. The FD/DOE-2 simulation also proved less-than-accurate in simulating the impact of changes in thermal mass as compared in previous published field measurements (Fathy, 1989).

6.3 Conclusions

The DOE-2 program showed limitations when applied for the case study, non-conditioned building. This may be related to the application of an abstract model in place of the actual house, or to the concept of splitting the house into inner and outer rings of zones, or to the thermal simulation modules that were made mainly to simulate conditioned buildings. In addition, The DOE-2 model showed a deficiency while simulating high thermal mass buildings which appeared as a convergence mis-match during the first week of the simulation.

The applied FD thermal network performed well in simulating a courtyard microclimate. Therefore the current simplified FD model is recommended for thermal analysis in courtyard research (e.g., perform computer simulations on any number of proposed courtyard design alternatives for reaching optimum thermal performance).

6.4 Recommendations for Future Research

The following are the recommendations in regard to simulations for courtyard houses, and simulations for courtyard microclimate.

Future work on the courtyard house thermal simulation needs to:

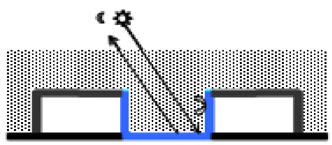
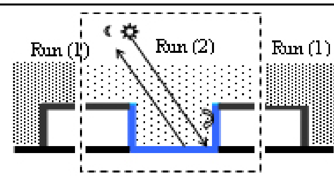
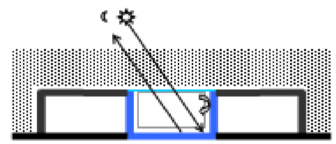
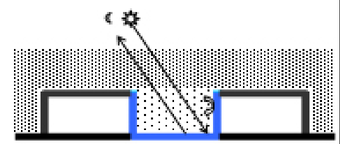
- Develop improved simulation software for buildings utilizing natural energy, such as natural convection, shading, and thermal mass.
- Develop procedures to more easily modify local weather files to reflect on-site conditions.
- Consider easy-to-use procedures for calculating and applying courtyard microclimates weather files to buildings with courtyards (i.e., two weather conditions per simulation).

In this regard Table 6.1 presents the current common simulations (base case) for a courtyard building and the simulation applied in this research (splitting the building into outer and inner rings of zones), along with two concepts for future simulations. One of these two concepts considers applying the courtyard microclimate weather file to the building envelope elements that are affected by it, and the other considers using a CFD simulation.

The Courtyard Microclimate Model may be developed further to include:

- 2-D thermal networking.
- A radiation network between courtyard envelope surfaces.
- Evaporation of water on surfaces, or misting systems (phase change); being a passive cooling element in hot arid climates.
- A coupled CFD model with the courtyard microclimate model to obtain better predictions related to airflow.

Table 6.1 Courtyard House Simulation Concepts

Concepts	Base case applied	Simulation 1 applied	Simulation 2 proposed	Detailed simulation proposed
Thermal simulation runs	One run- One ambient weather file	Two runs- (1) ambient weather file with exterior zone – (2) courtyard microclimate weather file with interior zone	One run – Two weather files; ambient and courtyard microclimate	One run – two weather files: courtyard microclimate (applying CFD) weather file and ambient weather file for the rest of the building
Graphic presentation				
Solar rad.	Yes with no microclimate	Yes	Yes	Yes
Sky rad.	Yes with no microclimate	Yes	Yes	Yes
Convection	Yes with no microclimate	Empirical convection	Empirical convection	Yes
Conduction	Yes with no microclimate	Yes	Yes	Yes
Advantages		Run (2) Courtyard envelope is exposed to courtyard microclimate		Courtyard envelope is exposed to the courtyard microclimate, while the rest of the building is exposed to ambient weather file
Disadvantages	Courtyard envelope is exposed to ambient weather file and not to microclimate weather file	- Run (2) the roof is also exposed to the courtyard microclimate - Final space temperatures are the average of interior and exterior zones		

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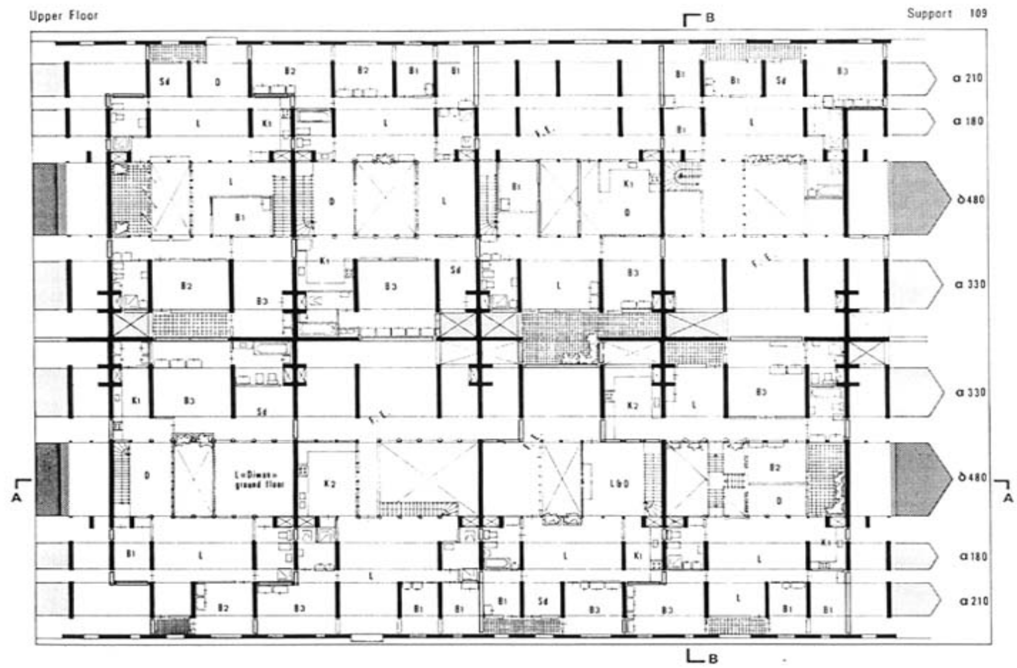
APPENDIX A

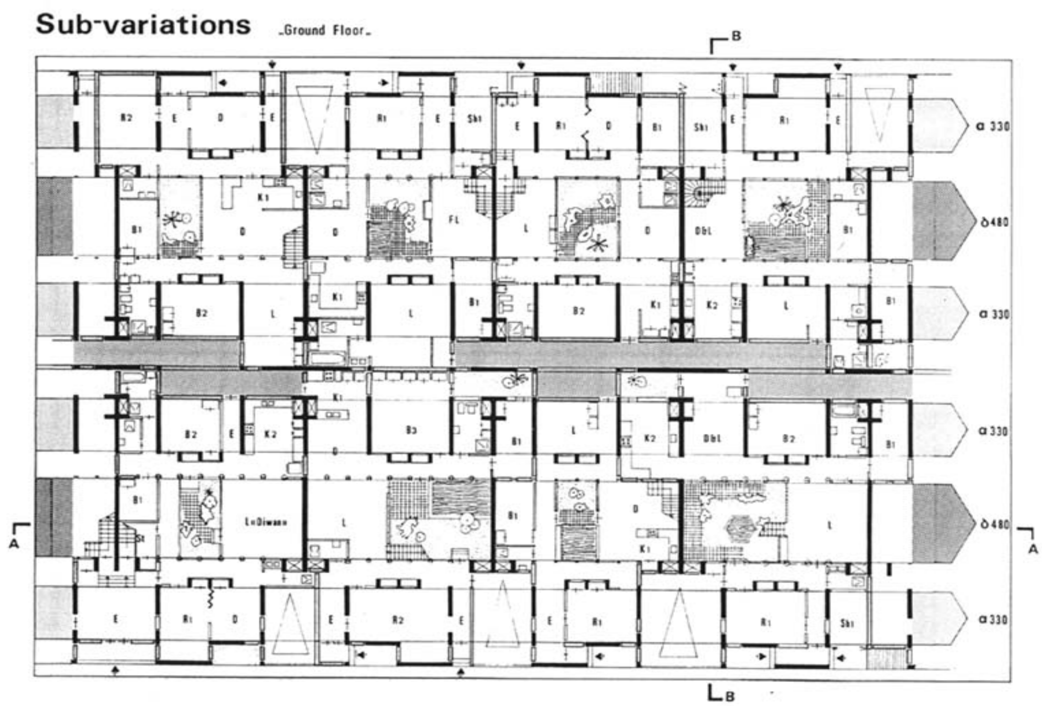
COURTYARD HOUSING CLUSTER PROJECTS

The negligence of the thermal mass factor is commonly reflected in proposed modern projects for urban courtyard housing clusters. On the following pages are four projects designed as academic models. A graph at the end of the Appendix includes a graphic comparison layout of the plans of these models along with the case study courtyard house showing the mass/void proportion across them.

Courtyard Housing cluster project



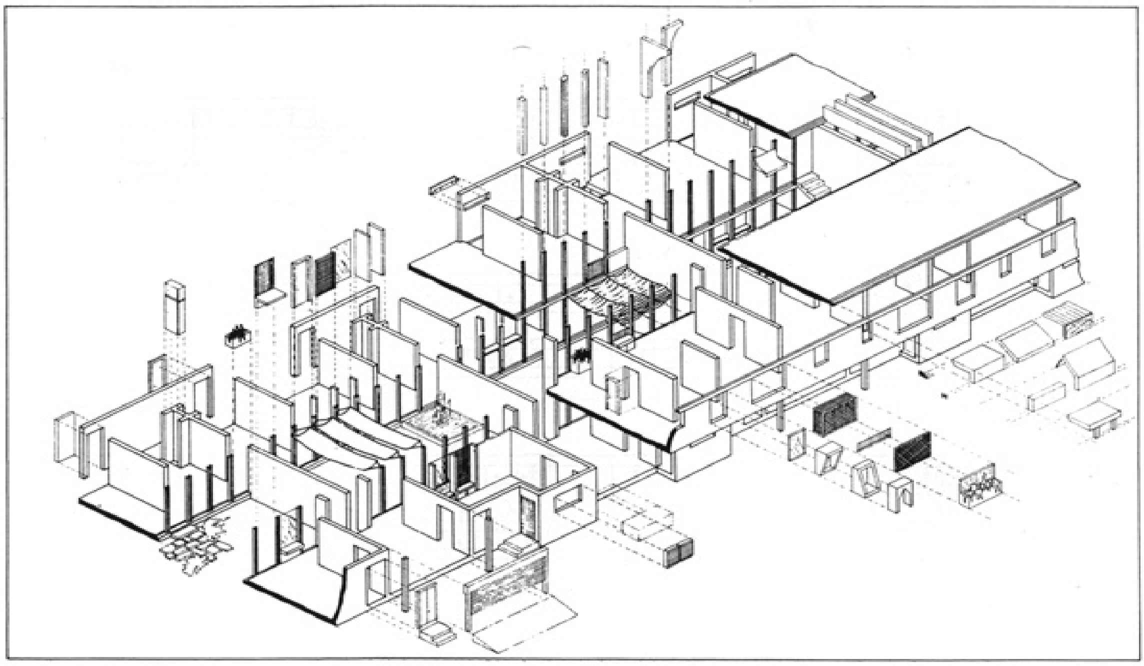
(1)

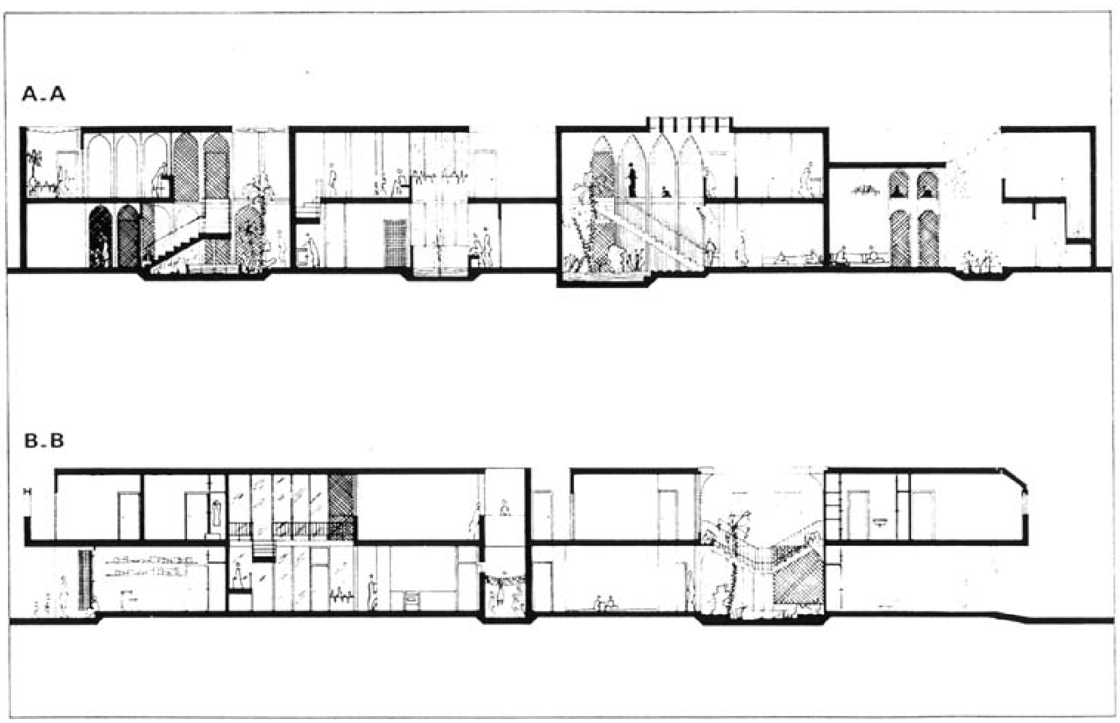


1a- Courtyard housing cluster project by Akbar (1981) – Ground floor and first floor plans.

Courtyard Housing cluster project (1),
(continued)

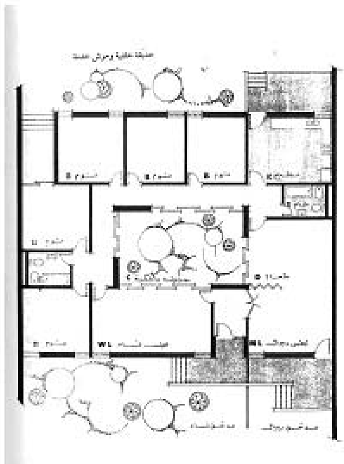
Detachable units

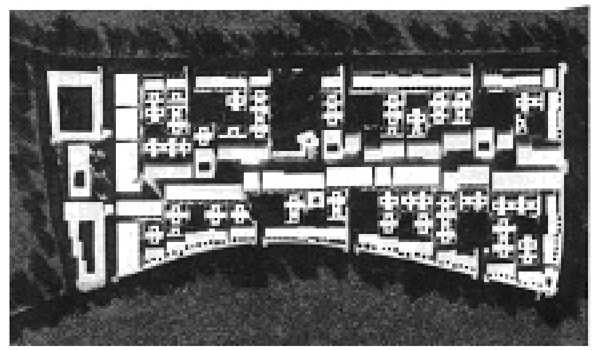




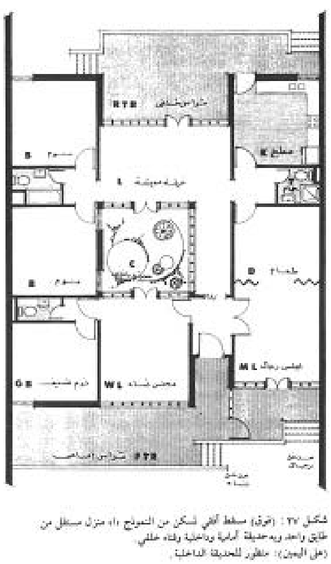
1b- Courtyard housing cluster project by Akbar (1981) – Isometric & Sections.

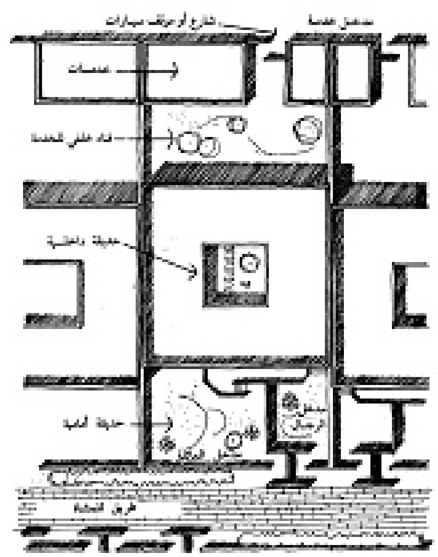
Courtyard Housing cluster project (2)

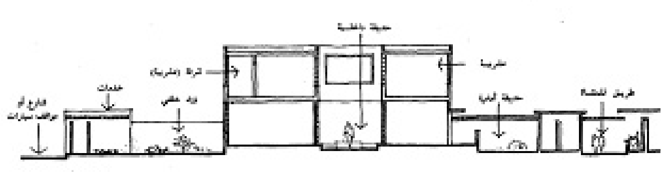




Master plan



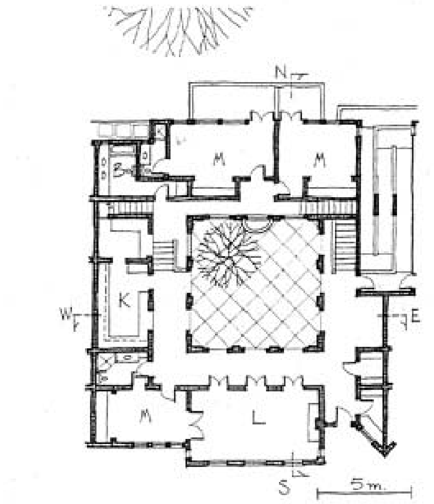




Site plan

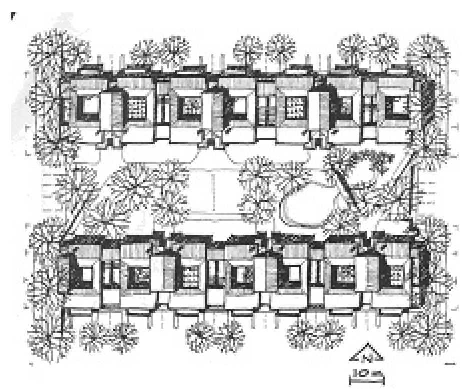
2- Courtyard housing neighborhood project by Moustapha and Costa (1987) –2 Plans, Section, & site plan.

Courtyard Housing cluster project (3)

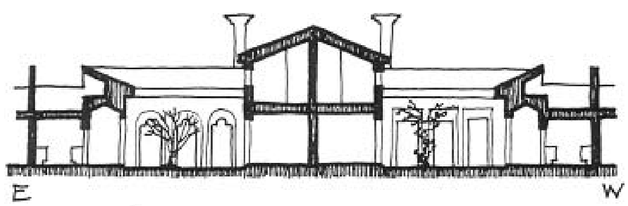


(11b)

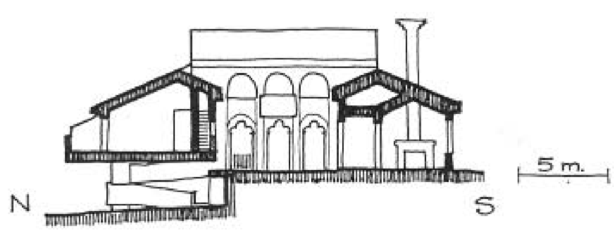
Plan



Site plan



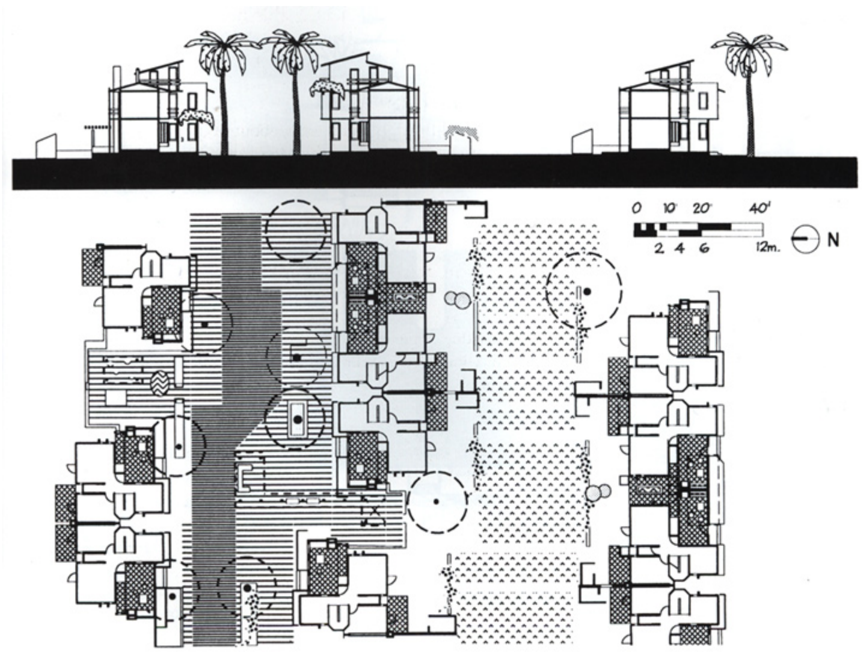
(11e)



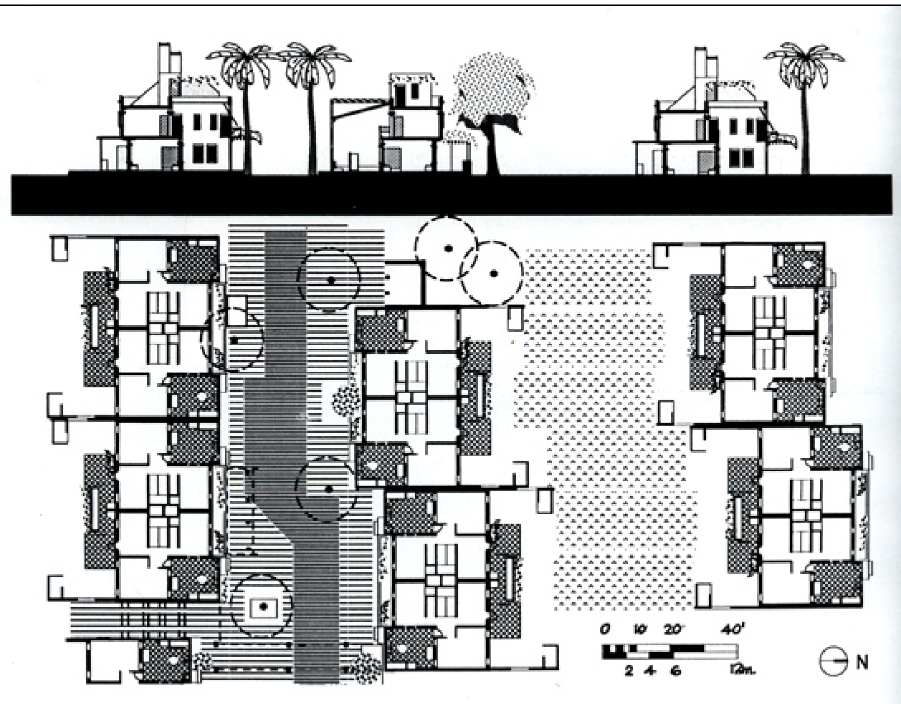
Sections

3- Courtyard housing cluster project by Reynolds (1995)

Courtyard Housing cluster projects (4)

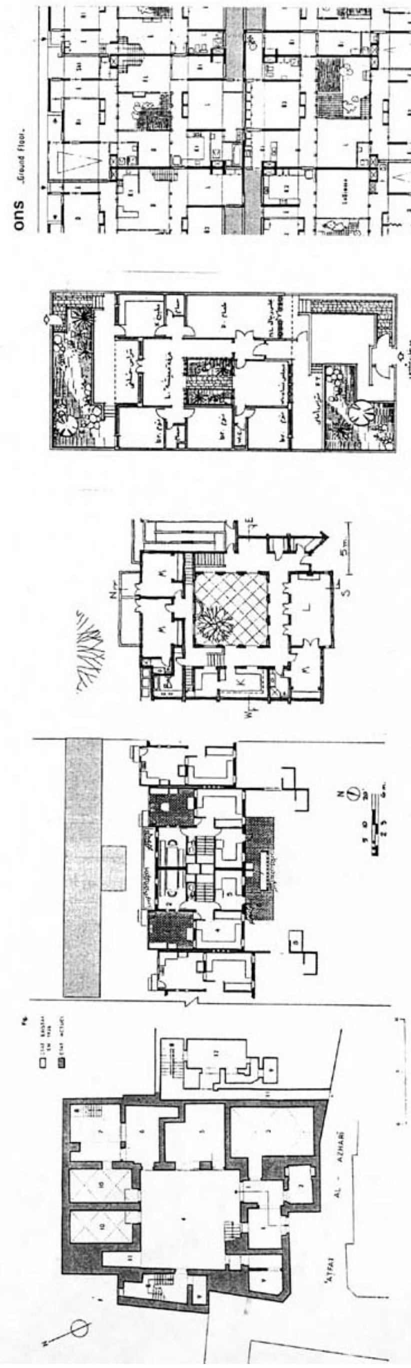


Housing proposal for hot and humid Adana, Turkey.



Housing proposal for hot and dry Urfa, Turkey.

3- Courtyard housing cluster project by Elmas, Can (1992)



Ground floor plans comparison
Note: Most of the ceiling of the ground floor case study house is made of limestone vaults.

APPENDIX B

SURVEY OF CAIRENE INDIGENOUS COURTYARD HOUSES

Comparison between available traditional courtyard houses in old Cairo A review was made on candidate courtyard houses:

House	Brief description	Advantages	Disadvantages
Sinari house	Two courtyards exists: main and one secondary (service).	The ground floor spaces: Reception Room – kitchen Have showed the coolest thermal conditions among the candidate houses. The house is not open for tourists thus having its doors closed, thus resembling a usual residential practice.	Glass leafs added to upper floor wood lattice windows. The large wind catcher is sealed with glass, which is expected to have a negative impact on the grand hall cooling performance.
Zeynab khatoon house	Three courtyards exist: main and two secondary (service). The house is almost a square shape.	The house has none of its original attached neighbor buildings. There exist assort alley on its southeast side.	The house is open for tourists, thus having its main door open all the time, in addition the courtyard is lit aft.er sunset for about two hours with spotlights at its top.
Harawi house	The house has one main courtyard. The may contain a service courtyard is ruined, waiting for restoration.	The Grand hall of the house showed low thermal conditions.	The house has a ruined section that needs restoration. The upper hall misses its dome, thus having no opening at its ceiling for air flow. The house has several sections that were built on the different stages of the house life with different architectural characteristics. The house does not have much of the original attached neighbor buildings.
Sabsheiry house	The house has one main courtyard.	The house is almost of a square shape, of moderate size, with four levels in height.	The house did not go through a restoration construction. Having some of its parts falling down. However the existing grand hall in the third floor did not show significant cooling potentials. The house is partially occupied by the family of the guard man.
Aly Labib	The house has two main courtyards. Some attached neighbor buildings still exist.	The grand hall is 7 ft. underground, with one side on the courtyard and the other on an outside garden, and its ceiling height about 12 ft. high. The only hall which is earth-sheltered among the candidate houses. Temperature inside the hall during a hot afternoons (Aug) was the coolest in the house (84 F), and among houses.	The house is composed of several apartments. The apartments are rented to artists, who rarely are present to allow for access to their apartments. The sample DB records of the house did not compete with other traditional houses (except for the underground hall).

Other traditional courtyard houses investigated and were not considered for thermal monitoring:

1. **Gretleiyah houses (2 houses)**: they were found to have high temperatures during the summer, this may be referred to the absence of the neighbor buildings form all sides.
2. **Sehemei house**: the house was too large in size and in number of spaces that would make it not suiTable for thermal simulation.
3. **Mostafa Gafaar house**: aft.er restoration the house has fixed glass panes on its openings, which would modify its original open window thermal performance.
4. **Gamal el-din el-Zahabi house**: the restoration of the house has added glass windows in a large section of the house in place of the wooden lattice windows.

Note: It was noticed that the coolest spot in any of the inspected houses was found in the ground

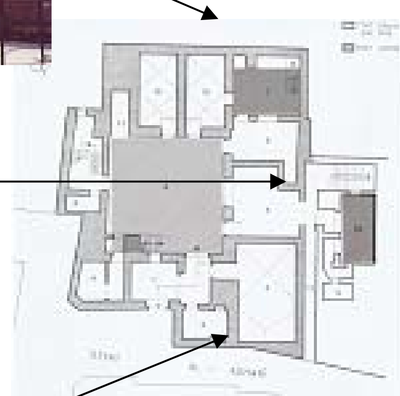
APPENDIX C

CASE STUDY: ZEINAB KHATUN INDIGENOUS COURTYARD HOUSE

The house dates back before 1468 AD. Building materials are lime stone, marble and wood. The land piece is about a square shape oriented 25 degrees East to the North. The house has one of its exterior walls on a short alley, and the other on a node formed by the intersection of three alleys. The other two sides used to have attached neighbor buildings, which do not currently exist, and it is now fully exposed to an open yard (of the current neighbor Al-Azhar University campus, opened ~975AD). The house currently has two secondary courtyards besides the main courtyard: the kitchen and the service courtyards. Living spaces concentrate on the South West and the North West wings of the house (onto the main courtyard). A winter hall and a summer hall are in each wing respectively, referring to seasonal migrations within the house. The third wing is composed mainly of the main entrance, above which there is the customary large terrace found in such houses that faces summer winds (North East), and a fourth narrow wing that used to have few secondary rooms. Preliminary work indicated that the reception room in the ground floor of the courtyard house showed a summer thermal performance similar to that of a living room of a north-facing modern apartment overlooking an 80 acres park. The apartment was located at the tenth floor and protected with 5 floors above it (~10 miles from the case study), and counted as among the coolest in Cairo.

Although other traditional courtyard houses showed lower DB records by about 3.5 F, this courtyard house was selected after considering the following advantages:

- It occupies an area of about 5000 sq. ft., which is comparable to modern land lots of single-family houses.
- Completely restored to original status (An extra section extending form the SE side of the house was originally missing since the time the house was acquired as an antique)
- It has winter and summer named living quarters (the employees who works in the house around the year mentioned that it has good thermal performance during the winter, contrary to the comments I received about other houses).



Ground floor plan

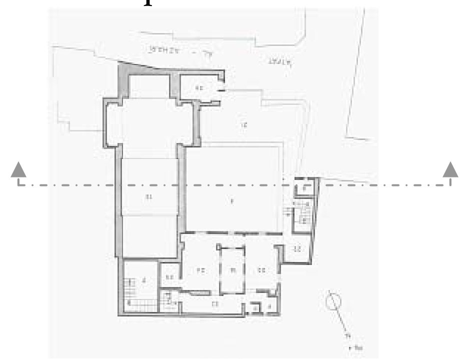
Thermal mass characteristics

It is worth noting that the case study courtyard house posses the following special characteristics as related to its thermal mass, which will be considered in the thermal simulation:

- The ground floor have the highest thermal mass to space volume ratio. It is the place where coolest temperatures were recorded in the summer daytime. Some spaces in this floor have heavy stone roofs of intersecting vaults.
- A wing located on the roof level of light thermal mass that includes a bed, service room, WC and kitchenette. The bedroom had ornaments with a bed size alcove that has wooden loft. reached by a vertical ladder (named by the current receptionists as the 'princess room'). The loft. has a ~3'x3' window with a pivoted wooden lattice screen. The service room is currently named by the receptionists as the 'maids room'.
- The summer hall of the 35 ft. high ceiling have marble floors and marble wall cladding to a height of ~4 ft., while the winter hall is less in height (~28 ft.) with limestone tiled floor which is believed to be covered by rugs. The summer hall have very small window to space volume ratio. The winter hall main façade on the courtyard have three large windows facing the southwest warm sunrays with side buttresses of heavy thermal mass. Both the summer and winter halls have no openings to the exterior ambient air, except for a top small dome having an octagonal base with clear-storey windows.

There are two spaces to be considered as free from heavy thermal mass: the first is a large loggia at the first floor overlooking the main courtyard that receives summer breaths, and the second is a rooftop (garden) wing with a small decorated room.

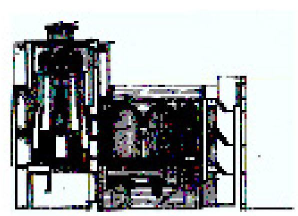
Architectural plans and sections



3rd floor plan

2nd floor plan

Ground floor plan



Section

APPENDIX D

DOE-2 SIMULATION INPUT FILE

```
$*********************************************************************************************
$       PROGRAM:                        DOE-2 SIMULATION INPUT FILE
$
$       LANGUAGE:                       DOE-2.1E BDL VERSION 119
$
$       SPONSOR:                        AMR  BAGNEID
$
$       PURPOSE:                        RESEARGH
$
$*********************************************************************************************

INPUT LOADS   ..

$**************************************TITLE**************************************************
TITLE           LINE-1 *COURTYARD RESEARCH*
                LINE-2 *COURTYARD HOUSE*
                LINE-4 *BASE CASE RUN*
                LINE-5 *RESEARCHER:  AMR BAGNEID*  ..

$*********************SET DEFAULT*************************************************************

SET-DEFAULT FOR SPACE-CONDITIONS FLOOR-WEIGHT = 0 ..   $TO ACTIVATE CUSTOM-WEIGHTING FACTORS
$NOTE THE MAX LIMESTONE THICKNESS DOE-2 MAY USE IS 1.3FT WHICH AFFECTED WALLS AND VAULT

$****************************RUN PERIOD*******************************************************

RUN-PERIOD     JAN 1 2001 THRU DEC 31 2001  ..

$****************************DIAGNOSTICS******************************************************
DIAGNOSTIC
         WARNINGS
         NO-ECHO                                  $DOE-2 DEFAULT = ECHO
         LIMITS                                   $DOE-2 DEFAULT(OR NO-LIMITS)
         SINGLE-SPACED  ..                        $DOE-2 DEFAULT(OR DOUBLE-SPACED)

$****************************ABORT************************************************************

ABORT    ERRORS  ..                                $DOE-2 DEFAULT(OR WARNINGS,CAUTIONS)

$****************************LOAD REPORTS*****************************************************

LOADS-REPORT   SUMMARY = (ALL-SUMMARY)
          VERIFICATION = (ALL-VERIFICATION)       ..                   $END OF LOADS REPORT

$*************************BUILDING LOCATION***************************************************

BUILDING-LOCATION
$       LATITUDE = 30.12              DOE-2.E MANUAL STATES THAT DEFAULT IS FROM WEATHER FILE
$       LONGITUDE = -31.4             DOE-2.E MANUAL STATES THAT DEFAULT IS FROM WEATHER FILE  $
$       TIME-ZONE = -2                DOE-2.E MANUAL STATES THAT DEFAULT IS FROM WEATHER FILE
        ALTITUDE = 75                            $
        GROSS-AREA= 5000                         $ SUM OF THE AREAS OF ALL
$                                                   CONDITIONED SPACES WHEN FLOOR-WEIGHT = 0
$                                                   OR JUST THE PERIMETER IF FLOOR-WEIGHT>0
        AZIMUTH = 25                             $ DOE-2 DEFAULT = 0
        SURF-TEMP-CALC = NO                      $DOE-2 DEFAULT,NEW COMMAND(DOE2.1E VER.107)
        DAYLIGHT-SAVINGS = NO                    $DOE-2 DEFAULT = YES
        HOLIDAY = NO                             $DOE-2 DEFAULT = YES
        GROUND-T = (57.2,59,62.6,68,71.6,81.32,85.1,86,84.2,78.26,65.66,62.6)
          X-REF = 0.0                               $DOE-2 DEFAULT,THESE COMMANDS ARE USED
          Y-REF = 0.0                               $CONJUNCTION WITH FIXED-SHADES COMMAND
                 ..                                 $END OF BUILDING LOCATION COMMAND

$*****************************MATERIALS*******************************************************

GYPSUM-PLASTER       = MATERIAL                     $DOE2.1E(MATERIALS LIBRARY)
                     THICKNESS    = .0833           $(FT)
```

```
                    CONDUCTIVITY = .133            $(BTU.FT/HR.FT^2.F)
                    DENSITY      = 45              $(LB/FT^3)
                    SPECIFIC-HEAT = .2   ..        $(BTU/LB.F)

MARBLE              = MATERIAL                     $DOE2.1E(MATERIALS LIBRARY)
                    THICKNESS    = 0.167           $(FT)
                    CONDUCTIVITY = 1.5             $(BTU.FT/HR.FT^2.F)
$                   RESISTANCE = 0.05
                    DENSITY      = 175             $(LB/FT^3)
                    SPECIFIC-HEAT = .21   ..       $(BTU/LB.F)

COMMON-BRICK-L1     = MATERIAL                     $DOE2.1E(MATERIALS LIBRARY)
                    THICKNESS    = 1.3             $(FT)
                    CONDUCTIVITY = .58             $(BTU.FT/HR.FT^2.F)
                    DENSITY      = 112             $(LB/FT^3)
                    SPECIFIC-HEAT = .2   ..        $(BTU/LB.F)

COMMON-BRICK-L2     = MATERIAL                     $DOE2.1E(MATERIALS LIBRARY)
                    THICKNESS    = 1               $(FT)
                    CONDUCTIVITY = .58             $(BTU.FT/HR.FT^2.F)
                    DENSITY      = 112             $(LB/FT^3)
                    SPECIFIC-HEAT = .2   ..        $(BTU/LB.F)

$STONE-GROUND        = MATERIAL              …..This was before applying wall chunks
$                    THICKNESS    = 1.3             (FT) max was found to be 1.3 ft
$                    CONDUCTIVITY = 1.04             (BTU.FT/HR.FT^2.F)
$                    DENSITY      = 140             (LB/FT^3)
$                    SPECIFIC-HEAT = 0.217  ..      (BTU/LB.F)

STONE-.2FEET        = MATERIAL                     $DOE2.1E(MATERIALS LIBRARY)
                    THICKNESS    = .2              $(FT)
                    CONDUCTIVITY = 1.04             $(BTU.FT/HR.FT^2.F)
                    DENSITY      = 140             $(LB/FT^3)
                    SPECIFIC-HEAT = 0.217   ..     $(BTU/LB.F)

STONE-.25FEET       = MATERIAL                     $DOE2.1E(MATERIALS LIBRARY)
                    THICKNESS    = .25             $(FT)
                    CONDUCTIVITY = 1.04             $(BTU.FT/HR.FT^2.F)
                    DENSITY      = 140             $(LB/FT^3)
                    SPECIFIC-HEAT = 0.217   ..     $(BTU/LB.F)

STONE-.5FEET        = MATERIAL                     $DOE2.1E(MATERIALS LIBRARY)
                    THICKNESS    = .5              $(FT)
                    CONDUCTIVITY = 1.04             $(BTU.FT/HR.FT^2.F)
                    DENSITY      = 140             $(LB/FT^3)
                    SPECIFIC-HEAT = 0.217   ..     $(BTU/LB.F)

STONE-.75FEET       = MATERIAL                     $DOE2.1E(MATERIALS LIBRARY)
                    THICKNESS    = .75               $(FT)
                    CONDUCTIVITY = 1.04             $(BTU.FT/HR.FT^2.F)
                    DENSITY      = 140             $(LB/FT^3)
                    SPECIFIC-HEAT = 0.217   ..     $(BTU/LB.F)

STONE-1FEET         = MATERIAL                     $DOE2.1E(MATERIALS LIBRARY)
                    THICKNESS    = 1               $(FT)
                    CONDUCTIVITY = 1.04             $(BTU.FT/HR.FT^2.F)
                    DENSITY      = 140             $(LB/FT^3)
                    SPECIFIC-HEAT = 0.217   ..     $(BTU/LB.F)

STONE-1.1FEET       = MATERIAL                     $DOE2.1E(MATERIALS LIBRARY)
                    THICKNESS    = 1.1             $(FT)
                    CONDUCTIVITY = 1.04             $(BTU.FT/HR.FT^2.F)
                    DENSITY      = 140             $(LB/FT^3)
                    SPECIFIC-HEAT = 0.217   ..      $(BTU/LB.F)

STONE-1.3FEET       = MATERIAL                     $DOE2.1E(MATERIALS LIBRARY)
                    THICKNESS    = 1.3             $(FT)MAX DOE-2 THICKNESS = 1.3
```

```
                     CONDUCTIVITY = 1.04            $(BTU.FT/HR.FT^2.F)
                     DENSITY      = 140             $(LB/FT^3)
                     SPECIFIC-HEAT = 0.217   ..      $(BTU/LB.F)

STONE-1.5FEET        = MATERIAL                     $DOE2.1E(MATERIALS LIBRARY)
                     THICKNESS    = 1.5             $(FT)MAX DOE-2 THICKNESS = 1.3
                     CONDUCTIVITY = 1.04            $(BTU.FT/HR.FT^2.F)
                     DENSITY      = 140             $(LB/FT^3)
                     SPECIFIC-HEAT = 0.217   ..      $(BTU/LB.F)

STONE-2FEET          = MATERIAL                     $DOE2.1E(MATERIALS LIBRARY)
                     THICKNESS    = 2               $(FT)MAX DOE-2 THICKNESS = 1.3
                     CONDUCTIVITY = 1.04            $(BTU.FT/HR.FT^2.F)
                     DENSITY      = 140             $(LB/FT^3)
                     SPECIFIC-HEAT = 0.217  ..      $(BTU/LB.F)

STONE-2.5FEET        = MATERIAL                     $DOE2.1E(MATERIALS LIBRARY)
                     THICKNESS    = 2.5             $(FT)MAX DOE-2 THICKNESS = 1.3
                     CONDUCTIVITY = 1.04            $(BTU.FT/HR.FT^2.F)
                     DENSITY      = 140             $(LB/FT^3)
                     SPECIFIC-HEAT = 0.217   ..     $(BTU/LB.F)

STONE-3FEET          = MATERIAL                     $DOE2.1E(MATERIALS LIBRARY)
                     THICKNESS    = 3               $(FT)MAX DOE-2 THICKNESS = 1.3
                     CONDUCTIVITY = 1.04            $(BTU.FT/HR.FT^2.F)
                     DENSITY      = 140             $(LB/FT^3)
                     SPECIFIC-HEAT = 0.217   ..     $(BTU/LB.F)

LIMESTONE            = MATERIAL                     $DOE2.1E(MATERIALS LIBRARY)
                     THICKNESS    = 0.167           $(FT)
                     CONDUCTIVITY = 1.04            $(BTU.FT/HR.FT^2.F)
                     DENSITY      = 140             $(LB/FT^3)
                     SPECIFIC-HEAT = 0.217  ..      $(BTU/LB.F)

LIMESTONE-COURT      = MATERIAL                     $DOE2.1E(MATERIALS LIBRARY)
                     THICKNESS    = 0.5             $(FT)
                     CONDUCTIVITY = 1.04            $(BTU.FT/HR.FT^2.F)
                     DENSITY      = 140             $(LB/FT^3)
                     SPECIFIC-HEAT = 0.217  ..      $(BTU/LB.F)

LIMESTONE-GROUNDFLR  = MATERIAL
                     THICKNESS  = 0.5
                     CONDUCTIVITY= 1.04
                     DENSITY  = 140
                     SPECIFIC-HEAT = 0.217  ..

SOIL-12IN            = MATERIAL
                     THICKNESS = 1.0
                     CONDUCTIVITY = 0.739
                     DENSITY = 90
                     SPECIFIC-HEAT = 0.22   ..

$ Slab-on-grade floors and underground walls

$SWO-UG-FRONT-1-FIC   =  MATERIAL    RESISTANCE =     ..  The  Rfic (fictitious) value
SWO-FLOOR-1-FIC      =  MATERIAL    RESISTANCE = 997.3  ..  $The  Rfic (fictitious) value

$SEO-UG-FRONT-1-FIC   =  MATERIAL    RESISTANCE =     ..
$SEO-UG-RIGHT-1-FIC   =  MATERIAL    RESISTANCE =     ..
$SEO-UG-BACK-1-FIC    =  MATERIAL    RESISTANCE =     ..
SEO-FLOOR-1-FIC       =  MATERIAL    RESISTANCE = 997.3  ..

$NEO-UG-BACK-1-FIC    =  MATERIAL    RESISTANCE =     ..
$NEO-UG-RIGHT-1-FIC   =  MATERIAL    RESISTANCE =     ..
$NEO-UG-LEFT-1-FIC    =  MATERIAL    RESISTANCE =     ..
NEO-FLOOR-1-FIC      =  MATERIAL    RESISTANCE = 997.3  ..
```

```
$NWO-UG-LEFT-1-FIC    =  MATERIAL    RESISTANCE =     ..
$NWO-UG-FRONT-1-FIC   =  MATERIAL    RESISTANCE =     ..
$NWO-UG-BACK-1-FIC    =  MATERIAL    RESISTANCE =     ..
NWO-FLOOR-1-FIC      =  MATERIAL    RESISTANCE = 997.3  ..

SWI-FLOOR-1-FIC      =  MATERIAL    RESISTANCE = 3.3    ..
SEI-FLOOR1-1-FIC     =  MATERIAL    RESISTANCE = 11.9   ..
NEI-FLOOR1-1-FIC     =  MATERIAL    RESISTANCE = 9.7    ..
NWI-FLOOR-1-FIC      =  MATERIAL    RESISTANCE = 3.1    ..

SAND                 = MATERIAL                        $DOE2.1E(MATERIALS LIBRARY)
                     THICKNESS    = 0.4167             $(FT)
                     CONDUCTIVITY = .19                $(BTU.FT/HR.FT^2.F)
                     DENSITY      = 94.6               $(LB/FT^3)
                     SPECIFIC-HEAT = 0.191  ..         $(BTU/LB.F)

SAND-ROOF            = MATERIAL                        $DOE2.1E(MATERIALS LIBRARY)
                     THICKNESS    = 0.5                $(FT)
                     CONDUCTIVITY = .19                $(BTU.FT/HR.FT^2.F)
                     DENSITY      = 94.6               $(LB/FT^3)
                     SPECIFIC-HEAT = 0.191  ..         $(BTU/LB.F)

WOOD-OAKWHITE        = MATERIAL                        $DOE2.1E(MATERIALS LIBRARY)
                     THICKNESS    = 0.21               $(FT)
                     CONDUCTIVITY = .102               $(BTU.FT/HR.FT^2.F)
                     DENSITY      = 47                 $(LB/FT^3)
                     SPECIFIC-HEAT = 0.57  ..          $(BTU/LB.F)

WOOD-ROOF            = MATERIAL                        $DOE2.1E(MATERIALS LIBRARY)
                     THICKNESS    = 0.167              $(FT)
                     CONDUCTIVITY = .102               $(BTU.FT/HR.FT^2.F)
                     DENSITY      = 47                 $(LB/FT^3)
                     SPECIFIC-HEAT = 0.57  ..          $(BTU/LB.F)

GYPSUM-WINDOW        = MATERIAL                        $DOE2.1E(MATERIALS LIBRARY)
                     THICKNESS     = .2083             $(FT)
                     CONDUCTIVITY  = .259              $(BTU.FT/HR.FT^2.F)
                     DENSITY       = 78                $(LB/FT^3)
                     SPECIFIC-HEAT = 0.26  ..          $(BTU/LB.F)

$GLASS-CLEAR         = MATERIAL                        DOE2.1E(MATERIALS LIBRARY)
$                    THICKNESS    = .2083              (FT) need to be .02083
$                    CONDUCTIVITY = .59                (BTU.FT/HR.FT^2.F)
$                    DENSITY      = 154                (LB/FT^3) DENSTY TOO SMALL?
$                    SPECIFIC-HEAT = 0.18  ..          (BTU/LB.F) - U-value=1.47 p.III50

$***************************LAYERS***************************************************************
ROOF-LAY1 = LAYERS
           INSIDE-FILM-RES = .76                     $VALUE FROM CLASS NOTES(HR.FT^2.F/BTU)
           MATERIAL = (WOOD-ROOF,SAND-ROOF,LIMESTONE)    ..     $CHANGED ORDER

WALL-LAY.2FT = LAYERS
           INSIDE-FILM-RES = .68                      $DOE-2 DEFAULT(0 TO 40)(HR.FT^2.F/BTU)
           MATERIAL = (STONE-.2FEET)   ..

WALL-LAY.25FT = LAYERS
           INSIDE-FILM-RES = .68                      $DOE-2 DEFAULT(0 TO 40)(HR.FT^2.F/BTU)
           MATERIAL = (STONE-.25FEET)   ..

WALL-LAY.5FT = LAYERS
           INSIDE-FILM-RES = .68                      $DOE-2 DEFAULT(0 TO 40)(HR.FT^2.F/BTU)
           MATERIAL = (STONE-.5FEET)   ..

WALL-LAY.75FT = LAYERS
           INSIDE-FILM-RES = .68                      $DOE-2 DEFAULT(0 TO 40)(HR.FT^2.F/BTU)
           MATERIAL = (STONE-.75FEET)   ..
```

```
WALL-LAY1FT = LAYERS
           INSIDE-FILM-RES = .68                     $DOE-2 DEFAULT(0 TO 40)(HR.FT^2.F/BTU)
           MATERIAL = (STONE-1FEET)   ..

WALL-LAY1.1FT = LAYERS
           INSIDE-FILM-RES = .68                     $DOE-2 DEFAULT(0 TO 40)(HR.FT^2.F/BTU)
           MATERIAL = (STONE-1.1FEET)   ..

WALL-LAY1.3FT = LAYERS
           INSIDE-FILM-RES = .68                     $DOE-2 DEFAULT(0 TO 40)(HR.FT^2.F/BTU)
           MATERIAL = (STONE-1.3FEET)   ..

WALL-LAY1.5FT = LAYERS
           INSIDE-FILM-RES = .68                     $DOE-2 DEFAULT(0 TO 40)(HR.FT^2.F/BTU)
           MATERIAL = (STONE-1.5FEET)   ..

WALL-LAY2FT = LAYERS
           INSIDE-FILM-RES = .68                     $DOE-2 DEFAULT(0 TO 40)(HR.FT^2.F/BTU)
           MATERIAL = (STONE-2FEET)   ..

WALL-LAY2.5FT = LAYERS
           INSIDE-FILM-RES = .68                     $DOE-2 DEFAULT(0 TO 40)(HR.FT^2.F/BTU)
           MATERIAL = (STONE-2.5FEET)   ..

WALL-LAY3FT = LAYERS
           INSIDE-FILM-RES = .68                     $DOE-2 DEFAULT(0 TO 40)(HR.FT^2.F/BTU)
           MATERIAL = (STONE-3FEET)   ..

WALL-LAY2 = LAYERS
           INSIDE-FILM-RES = .68                     $DOE-2 DEFAULT(0 TO 40)(HR.FT^2.F/BTU)
           MATERIAL = (GYPSUM-PLASTER,COMMON-BRICK-L1,GYPSUM-PLASTER)   ..

WALL-LAY3 = LAYERS
           INSIDE-FILM-RES = .68                     $DOE-2 DEFAULT(0 TO 40)(HR.FT^2.F/BTU)
           MATERIAL = (GYPSUM-PLASTER,COMMON-BRICK-L2,GYPSUM-PLASTER)   ..

CLNG-LAYVAULT = LAYERS
           INSIDE-FILM-RES = .92                     $(0 TO 40)(HR.FT^2.F/BTU)
           MATERIAL = (STONE-1.3FEET,SAND,LIMESTONE)   ..

CLNG-LAYWOOD = LAYERS
           INSIDE-FILM-RES = .92                     $(0 TO 40)(HR.FT^2.F/BTU)
           MATERIAL = (WOOD-ROOF,SAND-ROOF,LIMESTONE)    ..     $CHANGED ORDER

$CLNG-LAY21 = LAYERS
$          INSIDE-FILM-RES = .92                     (0 TO 40)(HR.FT^2.F/BTU)
$           MATERIAL = (LIMESTONE,SAND-ROOF,WOOD-ROOF)    ..     CHANGE ORDER
$CLNG-LAY22 = LAYERS                                FOR THE BATH
$          INSIDE-FILM-RES = .92                     (0 TO 40)(HR.FT^2.F/BTU)
$           MATERIAL = (STONE-1.1FEET )    ..

FLOOR-LAY1 = LAYERS
           INSIDE-FILM-RES = .61                     $(0 TO 40)(HR.FT^2.F/BTU)
           MATERIAL = (LIMESTONE-GROUNDFLR) ..

FLOOR-LAY2 = LAYERS
           INSIDE-FILM-RES = .61                     $(0 TO 40)(HR.FT^2.F/BTU)
           MATERIAL = (LIMESTONE-COURT) ..

DOOR-LAY1 = LAYERS
          MATERIAL = (WOOD-OAKWHITE)   ..

WINDOW-LAY2 = LAYERS              $GYPSUM WINDOW
          MATERIAL = (GYPSUM-WINDOW)   ..

$ Slab-on-grade floors and underground walls LAYERS
```

```
$SWO-UG-FRONT-1-LAY = LAYERS
$    MATERIAL = (SWO-UG-FRONT-1-FIC,SOIL-12IN,STONE-2FEET)
$    INSIDE-FILM-RES = 0.77  ..

SWO-FLOOR-1-LAY    = LAYERS
    MATERIAL = (SWO-FLOOR-1-FIC,SOIL-12IN,LIMESTONE-GROUNDFLR)
    INSIDE-FILM-RES = 0.77  ..

$SEO-UG-FRONT-1-LAY = LAYERS
$    MATERIAL = (SEO-UG-FRONT-1-FIC,SOIL-12IN,STONE-2FEET)
$    INSIDE-FILM-RES = 0.77  ..
$SEO-UG-RIGHT-1-LAY = LAYERS
$    MATERIAL = (SEO-UG-RIGHT-1-FIC,SOIL-12IN,STONE-2FEET)
$    INSIDE-FILM-RES = 0.77  ..
$SEO-UG-BACK-1-LAY  = LAYERS
$    MATERIAL = (SEO-UG-BACK-1-FIC,SOIL-12IN,STONE-2FEET)
$    INSIDE-FILM-RES = 0.77  ..

SEO-FLOOR-1-LAY    = LAYERS
    MATERIAL = (SEO-FLOOR-1-FIC,SOIL-12IN,LIMESTONE-GROUNDFLR)
    INSIDE-FILM-RES = 0.77  ..

$NEO-UG-BACK-1-LAY  = LAYERS
$    MATERIAL = (NEO-UG-BACK-1-FIC,SOIL-12IN,STONE-2FEET)
$    INSIDE-FILM-RES = 0.77  ..
$NEO-UG-RIGHT-1-LAY = LAYERS
$    MATERIAL = (NEO-UG-RIGHT-1-FIC,SOIL-12IN,STONE-2FEET)
$    INSIDE-FILM-RES = 0.77  ..
$NEO-UG-LEFT-1-LAY  = LAYERS
$    MATERIAL = (NEO-UG-LEFT-1-FIC,SOIL-12IN,STONE-2FEET)
$    INSIDE-FILM-RES = 0.77  ..

NEO-FLOOR-1-LAY = LAYERS
    MATERIAL = (NEO-FLOOR-1-FIC,SOIL-12IN,LIMESTONE-GROUNDFLR)
    INSIDE-FILM-RES = 0.77  ..

$NWO-UG-LEFT-1-LAY  = LAYERS
$    MATERIAL = (NWO-UG-LEFT-1-FIC,SOIL-12IN,STONE-2FEET)
$   INSIDE-FILM-RES = 0.77  ..
$NWO-UG-FRONT-1-LAY = LAYERS
$    MATERIAL = (NWO-UG-FRONT-1-FIC,SOIL-12IN,STONE-2FEET)
$    INSIDE-FILM-RES = 0.77  ..
$NWO-UG-BACK-1-LAY  = LAYERS
$    MATERIAL = (NWO-UG-BACK-1-FIC,SOIL-12IN,STONE-2FEET)
$    INSIDE-FILM-RES = 0.77  ..

NWO-FLOOR-1-LAY    = LAYERS
    MATERIAL = (NWO-FLOOR-1-FIC,SOIL-12IN,LIMESTONE-GROUNDFLR)
    INSIDE-FILM-RES = 0.77  ..

SWI-FLOOR-1-LAY  = LAYERS
    MATERIAL = (SWI-FLOOR-1-FIC,SOIL-12IN,LIMESTONE-GROUNDFLR)
    INSIDE-FILM-RES = 0.77  ..

SEI-FLOOR1-1-LAY = LAYERS
    MATERIAL = (SEI-FLOOR1-1-FIC,SOIL-12IN,LIMESTONE-GROUNDFLR)
    INSIDE-FILM-RES = 0.77  ..

NEI-FLOOR1-1-LAY = LAYERS
    MATERIAL = (NEI-FLOOR1-1-FIC,SOIL-12IN,LIMESTONE-GROUNDFLR)
    INSIDE-FILM-RES = 0.77  ..

NWI-FLOOR-1-LAY  = LAYERS
    MATERIAL = (NWI-FLOOR-1-FIC,SOIL-12IN,LIMESTONE-GROUNDFLR)
    INSIDE-FILM-RES = 0.77  ..

$FOR THE A/C BOX
```

```
WA-1 = LAYERS
  MATERIAL = (STONE-1.1FEET ) INSIDE-FILM-RES = 0.86 ..


$**************************CONSTRUCTION*********************************************************

ROOF-CON1 = CONSTRUCTION
           LAYERS = ROOF-LAY1
          ABSORPTANCE = .65
          ROUGHNESS = 3  ..


WALL-CON2 = CONSTRUCTION
          LAYERS = WALL-LAY2
          ABSORPTANCE = .65
          ROUGHNESS = 3  ..

WALL-CON3 = CONSTRUCTION
          LAYERS = WALL-LAY3
          ABSORPTANCE = .65
          ROUGHNESS = 3  ..

WALL-CON.2FT = CONSTRUCTION
          LAYERS = WALL-LAY.2FT  ..

WALL-CON.25FT = CONSTRUCTION
          LAYERS = WALL-LAY.25FT ..

WALL-CON.5FT = CONSTRUCTION
          LAYERS = WALL-LAY.5FT
          ABSORPTANCE = .65
          ROUGHNESS = 2  ..

WALL-CON.75FT = CONSTRUCTION
          LAYERS = WALL-LAY.75FT
          ABSORPTANCE = .65
          ROUGHNESS = 3  ..

WALL-CON1FT = CONSTRUCTION
          LAYERS = WALL-LAY1FT
          ABSORPTANCE = .65
          ROUGHNESS = 3  ..

WALL-CON1.1FT = CONSTRUCTION
          LAYERS = WALL-LAY1.1FT
          ABSORPTANCE = .65
          ROUGHNESS = 3  ..

WALL-CON1.3FT = CONSTRUCTION
          LAYERS = WALL-LAY1.3FT
          ABSORPTANCE = .65
          ROUGHNESS = 3  ..

WALL-CON1.5FT = CONSTRUCTION
          LAYERS = WALL-LAY1.5FT
          ABSORPTANCE = .65
          ROUGHNESS = 3  ..

WALL-CON2FT = CONSTRUCTION
          LAYERS = WALL-LAY2FT
          ABSORPTANCE = .65
          ROUGHNESS = 3  ..

WALL-CON2.5FT = CONSTRUCTION
          LAYERS = WALL-LAY2.5FT
          ABSORPTANCE = .65
          ROUGHNESS = 3  ..
```

```
WALL-CON3FT = CONSTRUCTION
          LAYERS = WALL-LAY3FT
          ABSORPTANCE = .65
          ROUGHNESS = 3  ..

CLNG-CONVAULT = CONSTRUCTION
           LAYERS = CLNG-LAYVAULT  ..

CLNG-CONWOOD  = CONSTRUCTION
          LAYERS = CLNG-LAYWOOD
          ABSORPTANCE = .65
          ROUGHNESS = 3  ..

$CLNG-CON21  = CONSTRUCTION
$           LAYERS = CLNG-LAY21  ..

$CLNG-CON22  = CONSTRUCTION
$           LAYERS = CLNG-LAY22  ..

FLOOR-CON1  = CONSTRUCTION
            LAYERS = FLOOR-LAY1 ..

FLOOR-CON2  = CONSTRUCTION
            LAYERS = FLOOR-LAY2 ..

DOOR-CON1 = CONSTRUCTION
          LAYERS = DOOR-LAY1  ..

WINDOW-CON2 = CONSTRUCTION             $GYPSUM WINDOW
          LAYERS = WINDOW-LAY2  ..

$ Slab-on-grade floors and underground walls CONSTRUCTION

$SWO-UG-FRONT-1-CON = CONSTRUCTION   LAYERS = SWO-UG-FRONT-1-LAY  ..
SWO-FLOOR-1-CON = CONSTRUCTION   LAYERS = SWO-FLOOR-1-LAY  ..

$SEO-UG-FRONT-1-CON = CONSTRUCTION   LAYERS = SEO-UG-FRONT-1-LAY  ..
$SEO-UG-RIGHT-1-CON = CONSTRUCTION   LAYERS = SEO-UG-RIGHT-1-LAY  ..
$SEO-UG-BACK-1-CON  = CONSTRUCTION   LAYERS = SEO-UG-BACK-1-LAY  ..
SEO-FLOOR-1-CON    = CONSTRUCTION   LAYERS = SEO-FLOOR-1-LAY  ..

$NEO-UG-BACK-1-CON  = CONSTRUCTION   LAYERS = NEO-UG-BACK-1-LAY  ..
$NEO-UG-RIGHT-1-CON = CONSTRUCTION   LAYERS = NEO-UG-RIGHT-1-LAY  ..
$NEO-UG-LEFT-1-CON  = CONSTRUCTION   LAYERS = NEO-UG-LEFT-1-LAY  ..
NEO-FLOOR-1-CON    = CONSTRUCTION   LAYERS = NEO-FLOOR-1-LAY  ..

$NWO-UG-LEFT-1-CON  = CONSTRUCTION   LAYERS = NWO-UG-LEFT-1-LAY  ..
$NWO-UG-FRONT-1-CON = CONSTRUCTION   LAYERS = NWO-UG-FRONT-1-LAY  ..
$NWO-UG-BACK-1-CON  = CONSTRUCTION   LAYERS = NWO-UG-BACK-1-LAY  ..
NWO-FLOOR-1-CON    = CONSTRUCTION   LAYERS = NWO-FLOOR-1-LAY  ..

SWI-FLOOR-1-CON  = CONSTRUCTION   LAYERS = SWI-FLOOR-1-LAY  ..

SEI-FLOOR1-1-CON = CONSTRUCTION   LAYERS = SEI-FLOOR1-1-LAY  ..

NEI-FLOOR1-1-CON = CONSTRUCTION   LAYERS = NEI-FLOOR1-1-LAY  ..

NWI-FLOOR-1-CON  = CONSTRUCTION   LAYERS = NWI-FLOOR-1-LAY  ..

$ FOR THE A/C BOX
WALL-1 = CONSTRUCTION  LAYERS=WA-1 ..
ROOF-1 = CONSTRUCTION  LAYERS=WA-1 ..
FLOOR-1= CONSTRUCTION  LAYERS=WA-1 ..

$********************* ALTERNATE WAYS FOR DEFINING GLASS TYPE ***********************************
GLASS-CLEAR          = GLASS-TYPE
```

```
                     GLASS-TYPE-CODE = 1
                     FRAME-CONDUCTANCE = 0.434
                     FRAME-ABS = 0.7  ..

$W-1 = GLASS-TYPE
$          GLASS-TYPE-CODE = 1000
$          FRAME-CONDUCTANCE = 0.434
$          FRAME-ABS = 0.7  ..

$************************  BUILDING  SHADES ****************************************************

GARDEN = BUILDING-SHADE
           X = 0  Y = -18.15  Z = 0
           HEIGHT = 19.8
           WIDTH = 59.4
           AZIMUTH = 180
           TRANSMITTANCE = 0
           TILT = 90
                    ..                             $END OF BUILDING-SHADE COMMAND
N-HOUSE-1 = BUILDING-SHADE
          X = 59.4    Y = -11.55  Z = 0
          HEIGHT = 28.05  WIDTH = 39.6
          AZIMUTH = 180
          TRANSMITTANCE = 0.0
          TILT = 90
                     ..                           $END OF BUILDING-SHADE COMMAND
N-HOUSE-2 = BUILDING-SHADE
          X =  59.4    Y = -67.65     Z = 0
          HEIGHT = 28.05
          WIDTH = 56.1
          AZIMUTH = 90
          TRANSMITTANCE = 0
          TILT = 90
                    ..                            $END OF BUILDING-SHADE COMMAND
SE-FENCE = BUILDING-SHADE
          X =  73.59
          Y = 0     Z = 0
          HEIGHT = 14.52
          WIDTH = 49.5
          AZIMUTH = 180
          TRANSMITTANCE = 0
          TILT = 90
                    ..                            $END OF BUILDING-SHADE COMMAND
NW-FENCE = BUILDING-SHADE
          X =  0
          Y = 44.55     Z = 0
          HEIGHT = 11.22
          WIDTH = 59.4
          AZIMUTH = 0
          TRANSMITTANCE = 0
          TILT = 90
                    ..                             $END OF BUILDING-SHADE COMMAND
SE-SHADE = BUILDING-SHADE
          X =  73.59
          Y = 0     Z = 17.82
          HEIGHT = 37.95
          WIDTH = 49.5
          AZIMUTH = 180
          TRANSMITTANCE = 0
          TILT = 0
                    ..                             $END OF BUILDING-SHADE COMMAND
MOSQUE-1 = BUILDING-SHADE
          X =  -13.2
          Y = 19.8     Z = 0
          HEIGHT = 31.35
          WIDTH = 59.4
          AZIMUTH = 270
```

```
          TRANSMITTANCE = 0
          TILT = 90
                    ..                              $END OF BUILDING-SHADE COMMAND
MOSQUE-2 = BUILDING-SHADE
          X =  -13.2
          Y = 19.8     Z = 0
          HEIGHT = 31.35
          WIDTH = 59.4
          AZIMUTH = 0
          TRANSMITTANCE = 0
          TILT = 90
                    ..                              $END OF BUILDING-SHADE COMMAND
MINARET-1 = BUILDING-SHADE
          X =  -13.2
          Y = -6.6     Z = 31.35
          HEIGHT = 31.35
          WIDTH = 6.6
          AZIMUTH = 270
          TRANSMITTANCE = 0
          TILT = 90
                    ..                              $END OF BUILDING-SHADE COMMAND
MINARET-2 = BUILDING-SHADE
          X =  -13.2
          Y = -6.6     Z = 31.35
          HEIGHT = 31.35
          WIDTH = 6.6
          AZIMUTH = 0
          TRANSMITTANCE = 0
          TILT = 90
                    ..                              $END OF BUILDING-SHADE

AZHAR-1   = BUILDING-SHADE
          X =  99
          Y = 89.1     Z = 0
          HEIGHT = 29.7
          WIDTH = 39.6
          AZIMUTH = 180
          TRANSMITTANCE = 0
          TILT = 90
                    ..                              $END OF BUILDING-SHADE COMMAND
AZHAR-2   = BUILDING-SHADE
          X =  99
          Y =  89.1     Z = 0
          HEIGHT = 29.7
          WIDTH = 79.2
          AZIMUTH = 90
          TRANSMITTANCE = 0
          TILT = 90
                    ..                              $END OF BUILDING-SHADE

$**********************************  SCREEN  SHADES  ********************************************

S-2-NEI-F-W1-GL = BUILDING-SHADE
          X = 9.24  Y = 54.4  Z = 14.22
          WIDTH = 7.5      HEIGHT = 6.5
          AZIMUTH = 180
          TRANSMITTANCE = 0.5                     $NARROW  GRID  SCREEN
          TILT = 90
          SHADE-SCHEDULE = B-SH-1    ..           $END OF BUILDING-SHADE COMMAND

S-2-NEI-F-W2-GL  = BUILDING-SHADE
          X = 26.24  Y = 54.4  Z = 14.22
          WIDTH = 6.5     HEIGHT = 6.5
          AZIMUTH = 180
          TRANSMITTANCE = 0.5                     $NARROW  GRID  SCREEN
          TILT = 90
          SHADE-SCHEDULE = B-SH-1    ..           $END OF BUILDING-SHADE COMMAND
```

```
S-2-NEI-F-W3-GL  = BUILDING-SHADE
          X = 42.74  Y = 54.4   Z = 14.22
          WIDTH = 7.5     HEIGHT = 6.5
          AZIMUTH = 180
          TRANSMITTANCE = 0.5                   $NARROW  GRID  SCREEN
          TILT = 90
          SHADE-SCHEDULE = B-SH-1    ..         $END OF BUILDING-SHADE COMMAND

S-3-NE-F-W1-GL  = BUILDING-SHADE
          X = 11.54  Y = 54.4   Z = 35.52
          WIDTH = 2.5      HEIGHT = 4
          AZIMUTH = 180
          TRANSMITTANCE = 0.5                   $NARROW  GRID  SCREEN
          TILT = 90
          SHADE-SCHEDULE = B-SH-1    ..         $END OF BUILDING-SHADE COMMAND

S-3-NE-F-W2-GL   = BUILDING-SHADE
          X = 28.59  Y = 54.4   Z = 36.02
          WIDTH = 2.4     HEIGHT = 2.4
          AZIMUTH = 180
          TRANSMITTANCE = 0.5                   $NARROW  GRID  SCREEN
          TILT = 90
          SHADE-SCHEDULE = B-SH-1    ..         $END OF BUILDING-SHADE COMMAND

S-3-NE-F-W3-GL   = BUILDING-SHADE
          X = 44.44  Y = 54.4   Z = 33.52
          WIDTH = 4    HEIGHT = 6
          AZIMUTH = 180
          TRANSMITTANCE = 0.5                   $NARROW  GRID  SCREEN
          TILT = 90
          SHADE-SCHEDULE = B-SH-1    ..         $END OF BUILDING-SHADE COMMAND

S-1-SEI-L-W-GL  = BUILDING-SHADE
          X = 50.44  Y = 41.95   Z= -1.32
          WIDTH = 7.5   HEIGHT = 9.9
          AZIMUTH = 270
          TRANSMITTANCE = 0.65                   $WIDE  GRID   GRID  SCREEN
          TILT = 90
          SHADE-SCHEDULE = B-SH-1    ..         $END OF BUILDING-SHADE COMMAND

S-2-SEI-L-W-GL  = BUILDING-SHADE
          X = 50.44   Y = 44.45  Z = 15.22
          WIDTH = 12.5   HEIGHT = 10
          AZIMUTH = 270
          TRANSMITTANCE = 0.5                   $NARROW  GRID  SCREEN
          TILT = 90
          SHADE-SCHEDULE = B-SH-1    ..         $END OF BUILDING-SHADE COMMAND

S-2-NWI-R-W-GL  = BUILDING-SHADE
          X = 41.29   Y = 0   Z = -2.97
          WIDTH = 1.7    HEIGHT = 2.8
          AZIMUTH = 90
          TRANSMITTANCE = 0.65                   $WIDE  GRID  SCREEN
          TILT = 90
          SHADE-SCHEDULE = B-SH-1    ..         $END OF BUILDING-SHADE COMMAND

S-1-SWI-B-W1-GL  = BUILDING-SHADE
          X = 35.49   Y = 13.25   Z = 1.03
          WIDTH = 3.3    HEIGHT = 4.3
          AZIMUTH = 0
          TRANSMITTANCE = 0.65                   $WIDE  GRID  SCREEN
          TILT = 90
          SHADE-SCHEDULE = B-SH-1    ..         $END OF BUILDING-SHADE COMMAND

S-1-SWI-B-W2-GL = BUILDING-SHADE
          X = 25.49   Y = 13.25    Z = 1.03
```

```
          WIDTH = 5.6    HEIGHT = 7
          AZIMUTH = 0
          TRANSMITTANCE = 0.65                   $WIDE  GRID  SCREEN
          TILT = 90
          SHADE-SCHEDULE = B-SH-1    ..         $END OF BUILDING-SHADE COMMAND

S-1-SWI-B-W3-GL  = BUILDING-SHADE
          X = 40.49   Y = 13.25   Z = 3.73
          WIDTH = 3    HEIGHT = 4.3
          AZIMUTH = 0
          TRANSMITTANCE = 0.65                   $WIDE  GRID  SCREEN
          TILT = 90
          SHADE-SCHEDULE = B-SH-1    ..         $END OF BUILDING-SHADE COMMAND

S-2-SWIR-B-W1-GL  = BUILDING-SHADE
          X = 43.49   Y = 13.25   Z = 13.72
          WIDTH = 4.6    HEIGHT = 6
          AZIMUTH = 0
          TRANSMITTANCE = 0.5                   $NARROW  GRID  SCREEN
          TILT = 90
          SHADE-SCHEDULE = B-SH-1    ..         $END OF BUILDING-SHADE COMMAND

S-2-SWIR-B-W2-GL  = BUILDING-SHADE
          X = 48.99   Y = 13.25   Z = 13.72
          WIDTH = 4.6    HEIGHT = 6
          AZIMUTH = 0
          TRANSMITTANCE = 0.5                   $NARROW  GRID  SCREEN
          TILT = 90
          SHADE-SCHEDULE = B-SH-1    ..         $END OF BUILDING-SHADE COMMAND

S-2-SWOR-F-W1-GL  = BUILDING-SHADE
          X = 39.59   Y = 0   Z = 16.17
          WIDTH = 5       HEIGHT = 6
          AZIMUTH = 180
          TRANSMITTANCE = 0.5                   $NARROW  GRID  SCREEN
          TILT = 90
          SHADE-SCHEDULE = B-SH-1    ..         $END OF BUILDING-SHADE COMMAND

S-2-SEO-F-W1-GL  = BUILDING-SHADE
          X = 58.44   Y = 0   Z = 16.17
          WIDTH = 5     HEIGHT = 6
          AZIMUTH = 180
          TRANSMITTANCE = 0.5                   $NARROW  GRID  SCREEN
          TILT = 90
          SHADE-SCHEDULE = B-SH-1    ..         $END OF BUILDING-SHADE COMMAND

S-2-SEO-F-W2-GL  = BUILDING-SHADE
          X = 65.44   Y = 0    Z = 16.17
          WIDTH = 5      HEIGHT = 6
          AZIMUTH = 180
          TRANSMITTANCE = 0.5                   $NARROW  GRID  SCREEN
          TILT = 90
          SHADE-SCHEDULE = B-SH-1    ..         $END OF BUILDING-SHADE COMMAND

S-2-NWO-L-W2-GL  = BUILDING-SHADE
          X = 0.0   Y = 9.3   Z = 16.17
          WIDTH = 4      HEIGHT = 9.3
          AZIMUTH = 270
          TRANSMITTANCE = 0.5                   $NARROW  GRID  SCREEN
          TILT = 90
          SHADE-SCHEDULE = B-SH-1    ..         $END OF BUILDING-SHADE COMMAND

S-2-NWO-L-W3-GL  = BUILDING-SHADE
          X = 0.0   Y = 21.3   Z = 16.17
          WIDTH = 4      HEIGHT = 9.3
          AZIMUTH = 270
          TRANSMITTANCE = 0.5                   $NARROW  GRID  SCREEN
```

```
          TILT = 90
          SHADE-SCHEDULE = B-SH-1    ..          $END OF BUILDING-SHADE COMMAND

$*********************************SCHEDULES******************************************************

$ OCCUPANCY SCHEDULE

OC-D = DAY-SCHEDULE  (1,8)(0.0)(9,21)(1.0)(22,24)(0.0) ..

OC-W = WEEK-SCHEDULE
          DAYS = (ALL)
          DAY-SCHEDULE = OC-D  ..

OC-Y = SCHEDULE       THRU DEC 31 WEEK-SCHEDULE = OC-W  ..

$ INFILTRATION SCHEDULE


$INFIL-D = DAY-SCHEDULE  (1,2)(27)(3,4)(34)(5,6)(40)(7,8)(34)(9,10)(27)(11,12)
$(20.5) (13,14)(14)(15,16)(7.5)(17,18)(1)(19,20)(7.5)(21,22)(14)(23,24)(20.5) ..

$INFIL-W = WEEK-SCHEDULE
$          DAYS = (ALL)
$          DAY-SCHEDULE = INFIL-D  ..

$INFIL-SCH = SCHEDULE       THRU DEC 31 WEEK-SCHEDULE = INFIL-W  ..

INFIL-SCH = SCHEDULE THRU DEC 31 (ALL) (1,24) (1)  ..

$ LIGHTING SCHEDULE

LIGHT-1 = DAY-SCHEDULE    (1,7)(1.0)(8,17)(0.0)(18,24)(1.0) ..

LIGHT-WEEK = WEEK-SCHEDULE
          DAYS = (MON,FRI)
          DAY-SCHEDULE = LIGHT-1
          DAYS = (WEH)
          DAY-SCHEDULE = LIGHT-1  ..

LIGHT-Y = SCHEDULE   THRU DEC 31 LIGHT-WEEK  ..

$  SHADING SCHEDULE

B-SH-1 = SCHEDULE  THRU DEC 31 (ALL) (1,24) (1) ..

$*************************GENERAL SPACE DEFINITION*********************************************
$***********AC-BOX*********************
$ FOR THE A/C BOX
 AC-BOX    = SPACE-CONDITIONS              $ THIS APPLIES TO THE CUBIC A/C BOX
           TEMPERATURE          = (84)            $AVERAGE VALUE OF MAX AND MIN
           PEOPLE-SCHEDULE      = OC-Y
           NUMBER-OF-PEOPLE     = 1

           PEOPLE-HEAT-GAIN     = 350             $ASHRAE STANDARD(BTU/HR),DOE-2 DEFAULT = 0
           LIGHTING-SCHEDULE    = LIGHT-Y
           LIGHTING-TYPE        = INCAND
           LIGHT-TO-SPACE       = 0.5
           INF-METHOD           = AIR-CHANGE       $DOE-2 DEFAULT=NONE,OR CRACK,RESIDENTIAL
           AIR-CHANGES/HR       = 0
           INF-SCHEDULE         = INFIL-SCH
           FLOOR-WEIGHT         =  0.0
           ZONE-TYPE            = CONDITIONED   ..

$***********ROOM-OPEN1*********************
ROOM-ACH1 = SPACE-CONDITIONS
           TEMPERATURE          = (74)            $AVERAGE VALUE OF MAX AND MIN
           PEOPLE-SCHEDULE      = OC-Y
```

```
          NUMBER-OF-PEOPLE     = 1
          PEOPLE-HEAT-GAIN     = 350            $ASHRAE STANDARD(BTU/HR),DOE-2 DEFAULT = 0
          LIGHTING-SCHEDULE    = LIGHT-Y
          LIGHTING-TYPE        = INCAND
          LIGHT-TO-SPACE       = 1.0
          INF-METHOD           = AIR-CHANGE      $DOE-2 DEFAULT=NONE,OR CRACK, RESIDENTIAL
          AIR-CHANGES/HR       = 2
          INF-SCHEDULE         = INFIL-SCH
          FLOOR-WEIGHT         =  0.0
          ZONE-TYPE            = UNCONDITIONED   ..

$***********ROOM-OPEN1*********************
ROOM-ACH15 = SPACE-CONDITIONS
          TEMPERATURE          = (74)           $AVERAGE VALUE OF MAX AND MIN
          PEOPLE-SCHEDULE      = OC-Y
          NUMBER-OF-PEOPLE     = 1
          PEOPLE-HEAT-GAIN     = 350            $ASHRAE STANDARD(BTU/HR),DOE-2 DEFAULT = 0
          LIGHTING-SCHEDULE    = LIGHT-Y
          LIGHTING-TYPE        = INCAND
          LIGHT-TO-SPACE       = 1.0
          INF-METHOD           = AIR-CHANGE      $DOE-2 DEFAULT=NONE,OR CRACK, RESIDENTIAL
          AIR-CHANGES/HR       = 10
          INF-SCHEDULE         = INFIL-SCH
          FLOOR-WEIGHT         =  0.0
          ZONE-TYPE            = UNCONDITIONED   ..

$FOR OUTER RING ZONE WITH FIXED AVG ANNUAL TEMP

$***********ROOM-OPEN1*********************
ROOM-OPEN1 = SPACE-CONDITIONS
          TEMPERATURE          = (90)           $AVERAGE VALUE OF MAX AND MIN
          PEOPLE-SCHEDULE      = OC-Y
          NUMBER-OF-PEOPLE     = 1
          PEOPLE-HEAT-GAIN     = 350            $ASHRAE STANDARD(BTU/HR),DOE-2 DEFAULT = 0
          LIGHTING-SCHEDULE    = LIGHT-Y
          LIGHTING-TYPE        = INCAND
          LIGHT-TO-SPACE       = 1.0
          INF-METHOD           = AIR-CHANGE      $DOE-2 DEFAULT=NONE,OR CRACK, RESIDENTIAL
          AIR-CHANGES/HR       = 15
          INF-SCHEDULE         = INFIL-SCH
          FLOOR-WEIGHT         =  0.0
          ZONE-TYPE            = UNCONDITIONED   ..

$FOR OUTER RING ZONE WITH FIXED AVG ANNUAL TEMP

$***********ROOM-OPEN1*********************
ROOM-OPEN73F = SPACE-CONDITIONS
          PEOPLE-SCHEDULE      = OC-Y
          NUMBER-OF-PEOPLE     = 1
          PEOPLE-HEAT-GAIN     = 350            $ASHRAE STANDARD(BTU/HR),DOE-2 DEFAULT = 0
          LIGHTING-SCHEDULE    = LIGHT-Y
          LIGHTING-TYPE        = INCAND
          LIGHT-TO-SPACE       = 1.0
          INF-METHOD           = AIR-CHANGE      $DOE-2 DEFAULT=NONE,OR CRACK, RESIDENTIAL
          AIR-CHANGES/HR       = 15
          INF-SCHEDULE         = INFIL-SCH
          FLOOR-WEIGHT         =  0.0
           TEMPERATURE =  (73)
          ZONE-TYPE            = UNCONDITIONED   ..


$***********ROOM-OPEN1*********************
ROOM-OPEN74F = SPACE-CONDITIONS
          PEOPLE-SCHEDULE      = OC-Y
          NUMBER-OF-PEOPLE     = 1
          PEOPLE-HEAT-GAIN     = 350            $ASHRAE STANDARD(BTU/HR),DOE-2 DEFAULT = 0
          LIGHTING-SCHEDULE    = LIGHT-Y
```

```
          LIGHTING-TYPE        = INCAND
          LIGHT-TO-SPACE       = 1.0
          INF-METHOD           = AIR-CHANGE       $DOE-2 DEFAULT=NONE,OR CRACK, RESIDENTIAL
          AIR-CHANGES/HR       = 15
          INF-SCHEDULE         = INFIL-SCH
          FLOOR-WEIGHT         =  0.0
           TEMPERATURE =  (74)
          ZONE-TYPE            = UNCONDITIONED   ..


$***********ROOM-OPEN1*********************
ROOM-OPEN75F = SPACE-CONDITIONS
          PEOPLE-SCHEDULE      = OC-Y
          NUMBER-OF-PEOPLE     = 1
          PEOPLE-HEAT-GAIN     = 350             $ASHRAE STANDARD(BTU/HR),DOE-2 DEFAULT = 0
          LIGHTING-SCHEDULE    = LIGHT-Y
          LIGHTING-TYPE        = INCAND
          LIGHT-TO-SPACE       = 1.0
          INF-METHOD           = AIR-CHANGE       $DOE-2 DEFAULT=NONE,OR CRACK, RESIDENTIAL
          AIR-CHANGES/HR       = 15
          INF-SCHEDULE         = INFIL-SCH
          FLOOR-WEIGHT         =  0.0
           TEMPERATURE =  (75)
          ZONE-TYPE            = UNCONDITIONED   ..


$***********ROOM-OPEN1*********************
ROOM-OPEN76F = SPACE-CONDITIONS
          PEOPLE-SCHEDULE      = OC-Y
          NUMBER-OF-PEOPLE     = 1
          PEOPLE-HEAT-GAIN     = 350             $ASHRAE STANDARD(BTU/HR),DOE-2 DEFAULT = 0
          LIGHTING-SCHEDULE    = LIGHT-Y
          LIGHTING-TYPE        = INCAND
          LIGHT-TO-SPACE       = 1.0
          INF-METHOD           = AIR-CHANGE       $DOE-2 DEFAULT=NONE,OR CRACK, RESIDENTIAL
          AIR-CHANGES/HR       = 15
          INF-SCHEDULE         = INFIL-SCH
          FLOOR-WEIGHT         =  0.0
           TEMPERATURE =  (76)
          ZONE-TYPE            = UNCONDITIONED   ..

$***********ROOM-OPEN1*********************
ROOM-OPEN77F = SPACE-CONDITIONS
          PEOPLE-SCHEDULE      = OC-Y
          NUMBER-OF-PEOPLE     = 1
          PEOPLE-HEAT-GAIN     = 350             $ASHRAE STANDARD(BTU/HR),DOE-2 DEFAULT = 0
          LIGHTING-SCHEDULE    = LIGHT-Y
          LIGHTING-TYPE        = INCAND
          LIGHT-TO-SPACE       = 1.0
          INF-METHOD           = AIR-CHANGE       $DOE-2 DEFAULT=NONE,OR CRACK, RESIDENTIAL
          AIR-CHANGES/HR       = 15
          INF-SCHEDULE         = INFIL-SCH
          FLOOR-WEIGHT         =  0.0
           TEMPERATURE =  (77)
          ZONE-TYPE            = UNCONDITIONED   ..

$***********ROOM-OPEN1*********************
ROOM-OPEN78F = SPACE-CONDITIONS
          PEOPLE-SCHEDULE      = OC-Y
          NUMBER-OF-PEOPLE     = 1
          PEOPLE-HEAT-GAIN     = 350             $ASHRAE STANDARD(BTU/HR),DOE-2 DEFAULT = 0
          LIGHTING-SCHEDULE    = LIGHT-Y
          LIGHTING-TYPE        = INCAND
          LIGHT-TO-SPACE       = 1.0
          INF-METHOD           = AIR-CHANGE       $DOE-2 DEFAULT=NONE,OR CRACK, RESIDENTIAL
          AIR-CHANGES/HR       = 15
          INF-SCHEDULE         = INFIL-SCH
```

```
          FLOOR-WEIGHT         =  0.0
           TEMPERATURE =  (78)
          ZONE-TYPE            = UNCONDITIONED   ..

$***********ROOM-OPEN1*********************
ROOM-OPEN79F = SPACE-CONDITIONS
          PEOPLE-SCHEDULE      = OC-Y
          NUMBER-OF-PEOPLE     = 1
          PEOPLE-HEAT-GAIN     = 350            $ASHRAE STANDARD(BTU/HR),DOE-2 DEFAULT = 0
          LIGHTING-SCHEDULE    = LIGHT-Y
          LIGHTING-TYPE        = INCAND
          LIGHT-TO-SPACE       = 1.0
          INF-METHOD           = AIR-CHANGE      $DOE-2 DEFAULT=NONE,OR CRACK, RESIDENTIAL
          AIR-CHANGES/HR       = 15
          INF-SCHEDULE         = INFIL-SCH
          FLOOR-WEIGHT         =  0.0
           TEMPERATURE =  (79)
          ZONE-TYPE            = UNCONDITIONED   ..

$***********ROOM-OPEN1*********************
ROOM-OPEN80F = SPACE-CONDITIONS
          PEOPLE-SCHEDULE      = OC-Y
          NUMBER-OF-PEOPLE     = 1
          PEOPLE-HEAT-GAIN     = 350            $ASHRAE STANDARD(BTU/HR),DOE-2 DEFAULT = 0
          LIGHTING-SCHEDULE    = LIGHT-Y
          LIGHTING-TYPE        = INCAND
          LIGHT-TO-SPACE       = 1.0
          INF-METHOD           = AIR-CHANGE      $DOE-2 DEFAULT=NONE,OR CRACK, RESIDENTIAL
          AIR-CHANGES/HR       = 15
          INF-SCHEDULE         = INFIL-SCH
          FLOOR-WEIGHT         =  0.0
           TEMPERATURE =  (80)
          ZONE-TYPE            = UNCONDITIONED   ..

$***********ROOM-OPEN1*********************
ROOM-OPEN81F = SPACE-CONDITIONS
          PEOPLE-SCHEDULE      = OC-Y
          NUMBER-OF-PEOPLE     = 1
          PEOPLE-HEAT-GAIN     = 350            $ASHRAE STANDARD(BTU/HR),DOE-2 DEFAULT = 0
          LIGHTING-SCHEDULE    = LIGHT-Y
          LIGHTING-TYPE        = INCAND
          LIGHT-TO-SPACE       = 1.0
          INF-METHOD           = AIR-CHANGE      $DOE-2 DEFAULT=NONE,OR CRACK, RESIDENTIAL
          AIR-CHANGES/HR       = 15
          INF-SCHEDULE         = INFIL-SCH
          FLOOR-WEIGHT         =  0.0
           TEMPERATURE =  (81)
          ZONE-TYPE            = UNCONDITIONED   ..

$***********ROOM-OPEN1*********************
ROOM-OPEN82F = SPACE-CONDITIONS
          PEOPLE-SCHEDULE      = OC-Y
          NUMBER-OF-PEOPLE     = 1
          PEOPLE-HEAT-GAIN     = 350            $ASHRAE STANDARD(BTU/HR),DOE-2 DEFAULT = 0
          LIGHTING-SCHEDULE    = LIGHT-Y
          LIGHTING-TYPE        = INCAND
          LIGHT-TO-SPACE       = 1.0
          INF-METHOD           = AIR-CHANGE      $DOE-2 DEFAULT=NONE,OR CRACK, RESIDENTIAL
          AIR-CHANGES/HR       = 15
          INF-SCHEDULE         = INFIL-SCH
          FLOOR-WEIGHT         =  0.0
           TEMPERATURE =  (82)
          ZONE-TYPE            = UNCONDITIONED   ..

$***********ROOM-OPEN1*********************
ROOM-OPEN83F = SPACE-CONDITIONS
          PEOPLE-SCHEDULE      = OC-Y
```

```
          NUMBER-OF-PEOPLE     = 1
          PEOPLE-HEAT-GAIN     = 350            $ASHRAE STANDARD(BTU/HR),DOE-2 DEFAULT = 0
          LIGHTING-SCHEDULE    = LIGHT-Y
          LIGHTING-TYPE        = INCAND
          LIGHT-TO-SPACE       = 1.0
          INF-METHOD           = AIR-CHANGE      $DOE-2 DEFAULT=NONE,OR CRACK, RESIDENTIAL
          AIR-CHANGES/HR       = 15
          INF-SCHEDULE         = INFIL-SCH
          FLOOR-WEIGHT         =  0.0
           TEMPERATURE =  (83)
          ZONE-TYPE            = UNCONDITIONED   ..

$***********ROOM-OPEN1********************
ROOM-OPEN84F = SPACE-CONDITIONS
          PEOPLE-SCHEDULE      = OC-Y
          NUMBER-OF-PEOPLE     = 1
          PEOPLE-HEAT-GAIN     = 350            $ASHRAE STANDARD(BTU/HR),DOE-2 DEFAULT = 0
          LIGHTING-SCHEDULE    = LIGHT-Y
          LIGHTING-TYPE        = INCAND
          LIGHT-TO-SPACE       = 1.0
          INF-METHOD           = AIR-CHANGE      $DOE-2 DEFAULT=NONE,OR CRACK, RESIDENTIAL
          AIR-CHANGES/HR       = 15
          INF-SCHEDULE         = INFIL-SCH
          FLOOR-WEIGHT         =  0.0
           TEMPERATURE = (84)
          ZONE-TYPE            = UNCONDITIONED   ..

$****************** SPECIFIC SPACE DETAILS - first floor ***********************************

$OOOOOOOOOOOOOOOOOOOOOO   O U T W A R D   Z O N E S  000000000000000000000000000O

$111-OOOOOOOOOOOOOOO [SWO] SOUTH WEST WING -FIRST FLOOR OOOOOOOOOOOOOOOOOOOOOOOOOOOO

SWO-1  = SPACE
         SPACE-CONDITIONS = ROOM-ACH15
         AREA = 272.25
         X = 9.24  Y = 0  Z = -2.97
         VOLUME = 3863.23
                  ..                          $END OF SPACE COMMANDS

SWO-FRONT-1 = EXTERIOR-WALL
             HEIGHT = 11.22
             WIDTH = 41.25
             X = 0   Y = 0   Z = 2.97
             AZIMUTH = 180
             SHADING-SURFACE = YES
             SHADING-DIVISIONS = 40
             CONSTRUCTION = WALL-CON2.5FT
             ..                                $END OF EXTERIOR WALL COMMAND

$ OPENINGS   L1-SWO-F    [ENTRANCE]

     1-SWO-F-D1     = DOOR
             X = 7.5       Y = 0
             WIDTH = 4.95   HEIGHT = 7.92
             SETBACK = 0.25
             CONSTRUCTION = DOOR-CON1
                      ..                       $END OF DOOR COMMAND

     1-SWO-F-W1     = DOOR
             WIDTH = 2      HEIGHT = 4
             X = 30            Y = 4.95
             SETBACK = 0.25
             CONSTRUCTION = DOOR-CON1
                      ..                       $END OF DOOR COMMAND
```

```
SWO-UG-FRONT-1 = UNDERGROUND-WALL
             HEIGHT = 2.97
             WIDTH = 41.25
             X = 0  Y = 0  Z = 0
             AZIMUTH = 180
             CONSTRUCTION =  WALL-CON1.3FT
              ..                                $END OF EXTERIOR WALL COMMAND

SWO-ADIAB-1 =  INTERIOR-WALL
               HEIGHT = 14.19   WIDTH =  41.25
               NEXT-TO  SWI-1
               TILT = 90
               X = 41.25      Y = 6.6        Z = 0
               AZIMUTH = 0
               CONSTRUCTION = WALL-CON1.3FT
                      ..

SWO-RIGHT-1 =  INTERIOR-WALL
               HEIGHT = 14.19   WIDTH =  6.6
               NEXT-TO  SEO-1
               TILT = 90
               X = 41.25     Y = 0.00   Z = 0
               AZIMUTH = 90
               CONSTRUCTION = WALL-CON1.3FT
                      ..

SWO-LEFT-1 = INTERIOR-WALL
               HEIGHT = 14.19      WIDTH =  6.6
               NEXT-TO  NWO-1
               TILT = 90
               CONSTRUCTION = WALL-CON1.3FT
               X = 0      Y = 6.6         Z = 0
               AZIMUTH = 270
                     ..

SWO-FLOOR-1     =   UNDERGROUND-FLOOR
               X = 0   Y = 0   Z = 0
               AREA = 272.25
                    TILT = 0
                    U-EFFECTIVE =  0.001
               CONSTRUCTION = SWO-FLOOR-1-CON
                      ..

SWO-CEILING-1 =   INTERIOR-WALL
              X = 0   Y = 0   Z = 14.19
              AREA = 272.25
              TILT = 0
              NEXT-TO  SWO-R2  $CHECK THIS, THE ROOM IS BELOW TWO SPACES SWO-2L&R
              CONSTRUCTION = CLNG-CONVAULT
                       ..                        $ END OF CEILING COMMAND

$111-OOOOOOOOOOOOOOOOOOOOOO [SEO] SOUTH EAST WING OOOOOOOOOOOOOOOOOOOOOOOOOOO

SEO-1 = SPACE
         SPACE-CONDITIONS = ROOM-ACH15
         AREA = 825.60
         X = 50.49  Y = 0.0  Z= -2.97
         VOLUME = 11715.24
                     ..                          $END OF SPACE COMMANDS

 SEO-FRONT-1 = EXTERIOR-WALL              $Before applying chunk walls
              HEIGHT = 11.22       WIDTH = 23.1
              X = 0   Y = 0   Z = 2.97
              AZIMUTH = 180
              SHADING-SURFACE = YES
              SHADING-DIVISIONS = 40
              CONSTRUCTION = WALL-CON3FT
```

```
               ..                              $END OF EXTERIOR WALL COMMAND

$OPENINGS   L1-SEO-F [RECEPTION HALL]  these were hampered for applying walls chunks

    1-SEO-F-W1   = DOOR
             WIDTH = 3.2    HEIGHT = 3.96
             X = 3            Y = 4.95
             SETBACK = 0.25
             CONSTRUCTION = DOOR-CON1
                      ..                        $END OF DOOR COMMAND

    1-SEO-F-W2   = DOOR
             WIDTH = 3.2    HEIGHT = 3.96
             X = 8            Y = 4.95
             SETBACK = 0.25
            CONSTRUCTION = DOOR-CON1
                      ..                        $END OF DOOR COMMAND

    1-SEO-F-D1   = DOOR
             WIDTH = 3.3    HEIGHT = 7.92
             X = 14           Y =0.00
             SETBACK = 0.25
             CONSTRUCTION = DOOR-CON1
                     ..                        $END OF DOOR COMMAND

    1-SEO-F-W3   = DOOR
             WIDTH = 3.2    HEIGHT = 3.96
             X = 19           Y = 4.95
             SETBACK = 0.25
            CONSTRUCTION = DOOR-CON1
                      ..                        $END OF DOOR COMMAND

SEO-UG-FRONT-1 = UNDERGROUND-WALL
               HEIGHT = 2.97          WIDTH = 23.1
               X = 0   Y = 0   Z = 0
               AZIMUTH = 180
               CONSTRUCTION = WALL-CON3FT
               ..                              $END OF EXTERIOR WALL COMMAND

SEO-RIGHT-1 =    EXTERIOR-WALL
                 HEIGHT = 11.22    WIDTH = 64.35
                 X = 23.1  Y = 0   Z = 2.97
                 AZIMUTH = 90
                 SHADING-SURFACE = YES
                 SHADING-DIVISIONS = 40
                 CONSTRUCTION = WALL-CON3FT
                   ..                          $END OF EXTERIOR WALL COMMAND

SEO-UGRIGHT-1 = UNDERGROUND-WALL
             HEIGHT = 2.97            WIDTH = 64.35
             X = 23.1  Y = 0   Z = 0
             AZIMUTH = 90
             CONSTRUCTION = WALL-CON3FT
             ..                                $END OF EXTERIOR WALL COMMAND

SEO-BACK-1  = EXTERIOR-WALL
             HEIGHT = 11.22             WIDTH = 16.5
             X = 23.1   Y = 64.35   Z = 2.97
             AZIMUTH = 0
             SHADING-SURFACE = YES
             SHADING-DIVISIONS = 40
             CONSTRUCTION = WALL-CON3FT
             ..                                $END OF EXTERIOR WALL COMMAND

SEO-UG-BACK-1 = UNDERGROUND-WALL
             HEIGHT = 2.97              WIDTH = 16.5
```

```
            X = 23.1   Y = 64.35   Z = 0
            AZIMUTH = 0
            CONSTRUCTION = WALL-CON3FT
            ..                                $END OF EXTERIOR WALL COMMAND

SEO-ADIAB-11 =        INTERIOR-WALL
              HEIGHT = 14.19   WIDTH =  11.55
              NEXT-TO  SEI-1
              TILT = 90
                   X = 11.55    Y = 6.6    Z = 0
              AZIMUTH = 0
           CONSTRUCTION = WALL-CON3FT
                   ..

SEO-ADIAB-12 =        INTERIOR-WALL
              HEIGHT = 14.19   WIDTH =  52.8
              NEXT-TO  SEI-1
              TILT = 90
                   X = 11.55    Y = 59.4    Z = 0
              AZIMUTH = 270
                   CONSTRUCTION = WALL-CON3FT
                   ..

SEO-ADIAB-13 =        INTERIOR-WALL
              HEIGHT = 14.19   WIDTH = 7
              NEXT-TO  SEI-1
              TILT = 90
                   X = 6.6    Y = 64.35    Z = 0
              AZIMUTH = 225
                   CONSTRUCTION = WALL-CON1.3FT
                   ..

SEO-FLOOR-1  = UNDERGROUND-FLOOR
              X = 0   Y = 0   Z = 0.00
              AREA = 825.60
                   U-EFFECTIVE = 0.001
                   CONSTRUCTION = SEO-FLOOR-1-CON
              TILT = 0
                    ..                      $END OF UNDERFGROUND FLOOR COMMAND

SEO-CEILING-1wood =   INTERIOR-WALL          $0.75 percent is wood  CLNG-CONWOOD
              AREA = 619.20
              X = 0   Y = 16.0875   Z = 14.19
              NEXT-TO  SEO-2
              TILT = 0
              CONSTRUCTION = CLNG-CONWOOD
                     ..                       $ END OF ceiling COMMAND
SEO-CEILING-1STONE =   INTERIOR-WALL       $0.25% of ceiling is limestone vault - CLNG-CONVAULT
              AREA = 206.40
              X = 0   Y = 0   Z = 14.19
              NEXT-TO  SEO-2
              TILT = 0
              CONSTRUCTION = CLNG-CONVAULT
                     ..                       $ END OF CEILING COMMAND

$****************** [NE] NORTH EAST WING ****************************************************

NEO-1    = SPACE
         SPACE-CONDITIONS = ROOM-ACH1
         AREA = 637.07
         X = 9.24  Y = 64.35  Z = -2.97
         VOLUME = 9039.95
                   ..                         $END OF SPACE COMMANDS

NEO-BACK-1 = EXTERIOR-WALL
            HEIGHT = 11.22     WIDTH = 47.85
            X = 47.85   Y = 16.5   Z = 2.97
```

```
              AZIMUTH = 0
              SHADING-SURFACE = YES
              SHADING-DIVISIONS = 40
              CONSTRUCTION = WALL-CON2FT
              ..                                $END OF EXTERIOR WALL COMMAND

NEO-UG-BACK-1 = UNDERGROUND-WALL
              HEIGHT = 2.97
              WIDTH = 47.85
              X = 47.85   Y = 16.5   Z = 0
              AZIMUTH = 0
              CONSTRUCTION = WALL-CON2FT              ..                              $END OF
EXTERIOR WALL COMMAND

NEO-RIGHT-1 = EXTERIOR-WALL
              HEIGHT = 11.22     WIDTH = 16.5
              X = 47.85   Y = 0   Z = 2.97
              AZIMUTH = 90
              SHADING-SURFACE = YES
              SHADING-DIVISIONS = 40
              CONSTRUCTION = WALL-CON2FT
              ..                                $END OF EXTERIOR WALL COMMAND

NEO-UG-RIGHT-1 = UNDERGROUND-WALL
              HEIGHT = 2.97
              WIDTH = 47.85
              X = 47.85   Y = 0   Z = 0
              AZIMUTH = 90
              CONSTRUCTION = WALL-CON2FT
               ..                               $END OF EXTERIOR WALL COMMAND

NEO-LEFT-1 = EXTERIOR-WALL
              HEIGHT = 11.22     WIDTH = 16.5
              X = 0   Y = 16.5   Z = 2.97
              AZIMUTH = 270
              SHADING-SURFACE = YES
              SHADING-DIVISIONS = 40
              CONSTRUCTION = WALL-CON3FT
              ..                                $END OF EXTERIOR WALL COMMAND

NEO-UG-LEFT-1 = UNDERGROUND-WALL
              HEIGHT = 2.97
              WIDTH = 16.5
              X = 0   Y = 16.5   Z = 0
              AZIMUTH = 270
              CONSTRUCTION = WALL-CON3FT
               ..                               $END OF EXTERIOR WALL COMMAND

NEO-ADIAB-11 =        INTERIOR-WALL
               HEIGHT = 14.19   WIDTH =  4.67
               NEXT-TO  NEI-1
               TILT = 90
                    X = 0    Y = 0    Z = 0
               AZIMUTH = 135
                    CONSTRUCTION = WALL-CON1FT
                    ..

NEO-ADIAB-12 =        INTERIOR-WALL
               HEIGHT = 14.19   WIDTH =  41.25
               NEXT-TO  NEI-1
               TILT = 90
                    X = 3.3    Y = 3.3    Z = 0
               AZIMUTH = 180
                    CONSTRUCTION = WALL-CON1FT
                    ..

NEO-ADIAB-13 =        INTERIOR-WALL
```

```
               HEIGHT = 14.19   WIDTH = 4.67
               NEXT-TO  NEI-1
               TILT = 90
                    X = 44.5    Y = 3.3     Z = 0
               AZIMUTH = 225
                    CONSTRUCTION = WALL-CON1FT
                    ..

NEO-FLOOR-1 = UNDERGROUND-FLOOR
              AREA = 637.07
              X = 0   Y = 0   Z = 0
              TILT = 0
              U-EFFECTIVE = 0.001
              CONSTRUCTION = NEO-FLOOR-1-CON
                      ..                        $ END OF FLOOR COMMAND

NEO-CEILING-1   =   INTERIOR-WALL
                    AREA = 637.07
                    X = 0   Y = 0   Z = 14.19
               NEXT-TO  NEO-2
                    TILT = 0
                    CONSTRUCTION = CLNG-CONVAULT
                      ..                        $ END OF CEILING COMMAND

$******[NWO] NORTH WEST WING*******************************************

NWO-1 = SPACE
         SPACE-CONDITIONS = ROOM-ACH1
         AREA = 333.13
         X = 0  Y = 0  Z = -2.97
         VOLUME = 4727.05
                    ..                          $END OF SPACE COMMANDS

NWO-ADIAB-11 =        INTERIOR-WALL
               HEIGHT = 14.19   WIDTH =  4.62
               NEXT-TO  NWI-1
               TILT = 90
                    X = 9.24    Y = 6.6    Z = 0
               AZIMUTH = 0
                    CONSTRUCTION = WALL-CON.2FT
                    ..

NWO-ADIAB-12 =        INTERIOR-WALL
               HEIGHT = 14.19   WIDTH = 53.13
               NEXT-TO  NWI-1
               TILT = 90
               X = 4.62    Y = 6.6    Z = 0
               AZIMUTH = 90
               CONSTRUCTION = WALL-CON.2FT
                    ..

NWO-ADIAB-13 =        INTERIOR-WALL
               HEIGHT = 14.19   WIDTH = 6.53
               NEXT-TO  NWI-1
               TILT = 90
               X = 4.62   Y = 59.73    Z = 0
               AZIMUTH = 135
               CONSTRUCTION = WALL-CON.2FT
                    ..

NWO-LEFT-1 = EXTERIOR-WALL
             HEIGHT = 11.22     WIDTH = 64.35
             X = 0   Y = 64.35   Z = 2.97
             AZIMUTH = 270
             SHADING-SURFACE = YES
             SHADING-DIVISIONS = 40
             CONSTRUCTION = WALL-CON2FT
```

```
                  ..                           $END OF EXTERIOR WALL COMMAND

$ OPENINGS L1-NWO-L [MOSQUE STREET WALL]

      1-NWO-L-W1    = DOOR
             WIDTH = 2        HEIGHT = 2.3
             X = 35           Y = 7
             SETBACK = 0.25
             CONSTRUCTION = DOOR-CON1
                 ..                          $END OF DOOR COMMAND

        1-NWO-L-W2    = DOOR
             WIDTH = 4        HEIGHT = 5.4
             X = 43           Y = 4.95
             SETBACK = 0.25
             CONSTRUCTION = DOOR-CON1
                 ..                          $END OF DOOR COMMAND

        1-NWO-L-W3    = DOOR
             WIDTH = 4     HEIGHT = 5.4
             X = 55           Y = 6.6
             SETBACK = 0.25
             CONSTRUCTION = DOOR-CON1
                      ..                     $END OF DOOR COMMAND

NWO-UG-LEFT-1 = UNDERGROUND-WALL
             HEIGHT = 2.97      WIDTH  = 64.35
             X = 0   Y = 64.35   Z = 0
             AZIMUTH = 270
             CONSTRUCTION = WALL-CON2FT
              ..                               $END OF EXTERIOR WALL COMMAND

NWO-FRONT-1 = EXTERIOR-WALL
             HEIGHT = 11.22     WIDTH = 9.24
             X = 0   Y = 0   Z = 2.97
             AZIMUTH = 180
             SHADING-SURFACE = YES
             SHADING-DIVISIONS = 40
             CONSTRUCTION = WALL-CON2.5FT
             ..                                $END OF EXTERIOR WALL COMMAND

$ OPENINGS   L1-NWO-F  [ENTRANCE-STREET  WALL]

    1-NW0-F-W1    = DOOR
             WIDTH = 3    HEIGHT = 4
             X = 1.75       Y = 4.95
             SETBACK = 0.25
             CONSTRUCTION = DOOR-CON1
                      ..                       $END OF DOOR COMMAND

    1-NW0-F-W2    = DOOR
             WIDTH = 3    HEIGHT = 4
             X = 6.23      Y = 4.95
             SETBACK = 0.25
             CONSTRUCTION = DOOR-CON1
                      ..                       $END OF DOOR COMMAND

NWO-UG-FRONT-1 = UNDERGROUND-WALL
             HEIGHT = 2.97
             WIDTH  = 9.24
             X = 0  Y = 0  Z = 0
             AZIMUTH = 180
             CONSTRUCTION = WALL-CON2.5FT
              ..                               $END OF EXTERIOR WALL COMMAND

NWO-BACK-1 = EXTERIOR-WALL
             HEIGHT = 11.22     WIDTH = 9.24
```

```
            X = 9.24   Y = 64.35   Z = 2.97
            AZIMUTH = 0
            SHADING-SURFACE = YES
            SHADING-DIVISIONS = 40
            CONSTRUCTION = WALL-CON2.5FT
            ..                              $END OF EXTERIOR WALL COMMAND

$ OPENINGS   L1-NWO-B    [W-STREET WALL]
    1-NW0-B-W    = DOOR
            WIDTH = 2    HEIGHT = 4
            X = 4          Y = 5
            SETBACK = 0.25
            CONSTRUCTION = DOOR-CON1
                     ..                     $END OF DOOR COMMAND

NWO-UG-BACK-1 = UNDERGROUND-WALL
            HEIGHT = 2.97
            WIDTH = 9.24
            X = 9.24   Y = 64.35   Z = 0
            AZIMUTH = 0
            CONSTRUCTION = WALL-CON2.5FT
            ..                              $END OF UNDERGROUND WALL COMMAND

NWO-FLOOR-1 = UNDERGROUND-FLOOR
            X = 0   Y = 0   Z = 0.00
             AREA = 333.13
            U-EFFECTIVE = 0.001
            CONSTRUCTION = NWO-FLOOR-1-CON
            $CONSTRUCTION = FLOOR-CON1    NEED TO ADD SAND UNDER THE LIMESTONE
            TILT = 0
             ..                  $END OF UNDERGROUND FLOOR COMMAND

NWO-CEILING-1 =   INTERIOR-WALL
             X = 0   Y = 0   Z = 14.19
             AREA = 333.13
             NEXT-TO  NWO-2
            TILT = 0
             CONSTRUCTION = CLNG-CONWOOD
              ..                     $ END OF CEILING COMMAND


$**SPECIFIC SPACE DETAILS-   S E C O N D   floor*************************

$**************** [SWO-2L] - SOUTH WEST TERRACE- SECOND FLOOR*********************
$*****[ SWO-R2] SOUH WEST ROOM*******************************************

 SWO-R2  = SPACE              $ this is line # 973
        SPACE-CONDITIONS = ROOM-ACH1
        X = 35.64  Y = 0  Z = 11.22
        AREA = 76
        VOLUME = 1509
         ..                         $END OF SPACE COMMANDS

SWO-FRONT-R =  EXTERIOR-WALL
                   HEIGHT = 19.8    WIDTH = 14.85
                   X = 0   Y = 0   Z = 0
                   AZIMUTH = 180
                   SHADING-SURFACE = YES
                   SHADING-DIVISIONS = 40
                   CONSTRUCTION = WALL-CON2FT
                   ..                               $END OF EXTERIOR WALL COMMAND

$ OPENINGS   L2-SWO-R  [ABOVE ENTRANCE]

     2-SWOR-F-W1-GL    = WINDOW              $Mashrabiah & Glass
            GLASS-TYPE = GLASS-CLEAR
            FRAME-WIDTH = 0.50                        $NARROW SCREEN
```

```
            SHADING-DIVISION = 40
            WIDTH = 5       HEIGHT = 6
            X = 4             Y = 4.95
            SETBACK = 0.0
                ..                        $END OF Mashrabiah & Glass COMMAND
   $ GYPSUM WINDOWS AUGMENTED WITH COLORED GLASS

    2-SWOR-F-W1-GP   = DOOR
            WIDTH = 2      HEIGHT = 3
            X = 3             Y = 13
            SETBACK = 0.25
            CONSTRUCTION = WINDOW-CON2
                     ..                    $END OF DOOR COMMAND

    2-SWOR-F-W2-GP  = DOOR
            WIDTH = 2      HEIGHT = 3
            X = 7            Y = 13
            SETBACK = 0.25
            CONSTRUCTION = WINDOW-CON2
                     ..                    $END OF DOOR COMMAND

     2-SWOR-F-W3-GP   = DOOR
            WIDTH = 2      HEIGHT = 3
            X = 11           Y = 13
            SETBACK = 0.25
            CONSTRUCTION = WINDOW-CON2
                     ..                    $END OF DOOR COMMAND

SWO-ADIAB-R21 =  INTERIOR-WALL
              HEIGHT = 19.8    WIDTH = 8.25
              NEXT-TO  SWI-R2
              TILT = 90
              X = 6.6        Y = 6.6        Z = 0
              AZIMUTH = 180
              CONSTRUCTION = WALL-CON2
                 ..

SWO-ADIAB-R22 =  INTERIOR-WALL
              HEIGHT = 19.8   WIDTH = 9.3337
              NEXT-TO  SWI-R2
              TILT = 90
              X = 0.0        Y = 0.0        Z = 0
              AZIMUTH = 135
                   CONSTRUCTION = WALL-CON2
                   ..

SWO-RIGHT-R2 = INTERIOR-WALL
              HEIGHT = 19.8   WIDTH =  6.6
              NEXT-TO  SEO-2
              TILT = 90
              X = 14.85     Y = 0.00   Z = 0
              AZIMUTH = 90
              CONSTRUCTION = WALL-CON2
                     ..

 SWO-ROOF = POLYGON
          (0,0) (14.85,0) (14.85,6.6) (6.6,6.6) ..

SWO-CEILING-R =   ROOF
              POLYGON =  SWO-ROOF
              X = 0   Y = 0   Z = 19.80
              AZIMUTH = 180
              TILT = 0
              SHADING-SURFACE = YES
              SHADING-DIVISIONS = 40
              CONSTRUCTION = CLNG-CONWOOD
                     ..                     $END OF ROOF COMMAND
```

```
$*****[SEO] SOUH EAST WING*********************************************

SEO-2 = SPACE
         SPACE-CONDITIONS = ROOM-ACH1
         AREA = 825.60
         X = 50.49  Y = 0.0  Z = 11.22
         VOLUME = 16347
                    ..                        $END OF SPACE COMMANDS

SEO-FRONT-2 = EXTERIOR-WALL
             HEIGHT = 19.8              WIDTH = 23.1
             X = 0  Y = 0   Z = 0
             AZIMUTH = 180
             SHADING-SURFACE = YES
             SHADING-DIVISIONS = 40
             CONSTRUCTION = WALL-CON2FT
             ..                               $END OF EXTERIOR WALL COMMAND

$ OPENINGS L2-SEO-F  [SUMMER HALL]

    2-SEO-F-W1-GL   =  WINDOW                  $MASHRABIA & GLASS
             GLASS-TYPE = GLASS-CLEAR
                      FRAME-WIDTH = 0.50                          $NARROW SCREEN
             SHADING-DIVISION = 40
             WIDTH = 5     HEIGHT = 6
             X = 8           Y = 4.95
             SETBACK = 0.25
                      ..                         $END OF MASHRABIA & GLASS COMMAND


    2-SEO-F-W2-GL   = WINDOW                   $MASHRABIA & GLASS
             GLASS-TYPE = GLASS-CLEAR
                      FRAME-WIDTH = 0.50                          $NARROW SCREEN
             SHADING-DIVISION = 40
             WIDTH = 5      HEIGHT = 6
             X = 15           Y = 4.95
             SETBACK = 0.25
                      ..                         $END OF MASHRABIA & GLASS COMMAND


SEO-RIGHT-2 =   EXTERIOR-WALL
               HEIGHT = 19.8    WIDTH = 64.35
                    X = 23.1  Y = 0   Z = 0
               AZIMUTH = 90
                    SHADING-SURFACE = YES
                    SHADING-DIVISIONS = 40
                    CONSTRUCTION = WALL-CON2FT
                    ..                                $END OF EXTERIOR WALL COMMAND

SEO-BACK-2  = EXTERIOR-WALL
                    HEIGHT = 19.8           WIDTH = 16.5
                    X = 23.1   Y = 64.35   Z = 0
                    AZIMUTH = 0
                    SHADING-SURFACE = YES
                    SHADING-DIVISIONS = 40
                    CONSTRUCTION = WALL-CON2FT
                    ..                        $END OF EXTERIOR WALL COMMAND

SEO-ADIAB-21 =        INTERIOR-WALL
               HEIGHT = 19.8   WIDTH =  11.55
               NEXT-TO  SEI-2
               TILT = 90
                    X = 11.55    Y = 6.6    Z = 0
               AZIMUTH = 0
                    CONSTRUCTION = WALL-CON.5FT
                    ..
```

```
SEO-ADIAB-22 =        INTERIOR-WALL
               HEIGHT = 19.8   WIDTH =  52.8
               NEXT-TO  SEI-2
               TILT = 90
                    X = 11.55    Y = 59.4    Z = 0
               AZIMUTH = 270
                    CONSTRUCTION = WALL-CON.5FT
                    ..

SEO-ADIAB-23 =        INTERIOR-WALL
               HEIGHT = 19.8   WIDTH = 7
               NEXT-TO  SEI-2
               TILT = 90
                    X = 6.6    Y = 64.35    Z = 0
               AZIMUTH = 225
                    CONSTRUCTION = WALL-CON.5FT
                    ..

SEO-CEILING-2WOOD =   INTERIOR-WALL        $0.75 percent is wood  CLNG-CONWOOD
               AREA = 619.20
               X = 0   Y = 16.0875   Z = 19.80
               NEXT-TO  SE-3
               TILT = 0
               CONSTRUCTION = CLNG-CONWOOD
                      ..                       $ END OF ceiling COMMAND

SEO-CEILING-2STONE =   INTERIOR-WALL     $0.25 percent of ceiling is limestone vault - CLNG-
CONVAULT
               AREA = 206.40
               X = 0   Y = 0   Z = 19.80
               NEXT-TO  SE-3
               TILT = 0
               CONSTRUCTION = CLNG-CONVAULT
                      ..                       $ END OF CEILING COMMAND

$*********[NE] NORTH EAST WING***********************************************

NEO-2    = SPACE
         SPACE-CONDITIONS = ROOM-ACH1
         AREA = 637.07
         X = 9.24  Y = 64.35  Z = 11.22
         VOLUME = 12614
                    ..                         $END OF SPACE COMMANDS

NEO-BACK-2 = EXTERIOR-WALL
             HEIGHT = 19.8     WIDTH = 47.85
             X = 47.85   Y = 16.5   Z = 0
             AZIMUTH = 0
             SHADING-SURFACE = YES
             SHADING-DIVISIONS = 40
             CONSTRUCTION = WALL-CON2.5FT
             ..                                $END OF EXTERIOR WALL COMMAND

$ OPENINGS   L2-NEO-B   [WINTER HALL SERVICE AREA]
     $ Low windows
      2-NEO-B-W1    = DOOR
             WIDTH  = 2     HEIGHT = 3
             X = 31           Y = 5
             SETBACK = 0.5
             CONSTRUCTION = DOOR-CON1
                      ..                       $END OF DOOR COMMAND

      2-NEO-B-W2    = DOOR
             WIDTH = 2      HEIGHT = 3
             X = 40           Y = 5
             SETBACK = 0.5
```

```
            CONSTRUCTION = DOOR-CON1
                     ..                        $END OF DOOR COMMAND
    $ High windows
     2-NEO-B-W3    = DOOR
            WIDTH = 3.5     HEIGHT = 3.5
            X = 20            Y = 12
            SETBACK = 0.5
            CONSTRUCTION = DOOR-CON1
                     ..                        $END OF DOOR COMMAND

     2-NEO-B-W4    = DOOR
            WIDTH = 3.5     HEIGHT = 3.5
            X = 25            Y = 12
            SETBACK = 0.5
            CONSTRUCTION = DOOR-CON1
                     ..                        $END OF DOOR COMMAND
     2-NEO-B-W5    = DOOR
            WIDTH = 2      HEIGHT = 2
            X = 31           Y = 13
            SETBACK = 0.5
            CONSTRUCTION = DOOR-CON1
                     ..                        $END OF DOOR COMMAND

     2-NEO-B-W6    = DOOR
            WIDTH = 2      HEIGHT = 3
            X = 40           Y = 12
            SETBACK = 0.5
            CONSTRUCTION = DOOR-CON1
                     ..                        $END OF DOOR COMMAND

NEO-RIGHT-2 = EXTERIOR-WALL
            HEIGHT = 19.8     WIDTH = 16.5
            X = 47.85   Y = 0   Z = 0
            AZIMUTH = 90
            SHADING-SURFACE = YES
            SHADING-DIVISIONS = 40
            CONSTRUCTION = WALL-CON2.5FT
            ..                                 $END OF EXTERIOR WALL COMMAND

NEO-LEFT-2 = EXTERIOR-WALL
            HEIGHT = 19.8     WIDTH = 16.5
            X = 0   Y = 16.5   Z = 0
            AZIMUTH = 270
            SHADING-SURFACE = YES
            SHADING-DIVISIONS = 40
            CONSTRUCTION = WALL-CON2.5FT
            ..                                 $END OF EXTERIOR WALL COMMAND

$ OPENINGS   L2-NEO-L    [WINTER HALL SERVICE AREA]

    2-NEO-L-W1   = DOOR
            WIDTH  = 2.5    HEIGHT = 4
            X = 6.5         Y = 3
            SETBACK = 0.5
            CONSTRUCTION = DOOR-CON1
                     ..                        $END OF DOOR COMMAND

     2-NEO-L-W2    = DOOR
            WIDTH  = 2.5    HEIGHT = 3.5
            X = 6.5         Y = 10
            SETBACK = 0.5
            CONSTRUCTION = DOOR-CON1
                     ..                        $END OF DOOR COMMAND


NEO-ADIAB-21 =         INTERIOR-WALL
                   HEIGHT = 19.8   WIDTH =  4.67
```

```
                    NEXT-TO NEI-2
                    TILT = 90
                    X = 0    Y = 0           Z = 0
                    AZIMUTH = 135
                    CONSTRUCTION = WALL-CON1FT
                    ..

NEO-ADIAB-22 =        INTERIOR-WALL
               HEIGHT = 19.8   WIDTH =  41.25
                    NEXT-TO  NEI-2
               TILT = 90
                    X = 3.3    Y = 3.3    Z = 0
               AZIMUTH = 180
                    CONSTRUCTION = WALL-CON1FT
                    ..

NEO-ADIAB-23 =        INTERIOR-WALL
               HEIGHT = 19.8   WIDTH = 4.67
                    NEXT-TO  NEI-2
               TILT = 90
                    X = 44.5    Y = 3.3    Z = 0
               AZIMUTH = 225
                    CONSTRUCTION = WALL-CON1FT
                    ..

NEO-CEILING-2 =  INTERIOR-WALL           $ ceiling is wood  CLNG-CONWOOD
               AREA = 825
               X = 0   Y = 0   Z = 19.80
               TILT = 0
               NEXT-TO = SE-3
                    CONSTRUCTION = CLNG-CONWOOD
                      ..                       $ END OF CEILING COMMAND

$*****[NWO] NORTH WEST  WING****************************************************

NWO-2 = SPACE
         SPACE-CONDITIONS = ROOM-ACH15
         AREA = 307.97
         X = 0  Y = 0  Z = 11.22
         VOLUME = 6098
                    ..                         $END OF SPACE COMMANDS

NWO-ADIAB-21= INTERIOR-WALL
                    HEIGHT = 19.8      WIDTH = 6.53
                    X = 4.62   Y = 4.62   Z = 0
                    NEXT-TO  NWI-2
                    TILT = 90
                    AZIMUTH = 225
                    CONSTRUCTION = WALL-CON.5FT
                    ..                                $END OF INTERIOR WALL COMMAND

NWO-ADIAB-22 = INTERIOR-WALL
                      HEIGHT = 19.8   WIDTH = 55.11
                    NEXT-TO  NWI-2
                      TILT = 90
                      X = 4.62    Y = 4.62    Z = 0
                      AZIMUTH = 90
                      CONSTRUCTION = WALL-CON.5FT
                    ..

NWO-ADIAB-23 = INTERIOR-WALL
                      HEIGHT = 19.8   WIDTH = 6.53
                    NEXT-TO  NWI-2
                      TILT = 90
                      X = 4.62    Y = 59.73         Z = 0
                      AZIMUTH = 135
                      CONSTRUCTION = WALL-CON.5FT
```

```
                    ..

NWO-LEFT-2 = EXTERIOR-WALL
             HEIGHT = 19.8     WIDTH = 64.35
             X = 0   Y = 64.35   Z = 0
             AZIMUTH = 270
             SHADING-SURFACE = YES
             SHADING-DIVISIONS = 40
             CONSTRUCTION = WALL-CON2FT
             ..                              $END OF EXTERIOR WALL COMMAND

$ OPENINGS   L2-NWO-L [MOSQUE-STREET WALL]
    L2-NWO-L-W1      = DOOR
             WIDTH = 2      HEIGHT = 2.3
             X = 35           Y = 7
             SETBACK = 0.25
             CONSTRUCTION = DOOR-CON1
                 ..                            $END OF DOOR COMMAND

    L2-NWO-L-W2-GL      = WINDOW               $MASHRABIAH & GLASS
             GLASS-TYPE = GLASS-CLEAR
             FRAME-WIDTH = 0.50                $NARROW SCREEN
             SHADING-DIVISION = 40
             WIDTH = 4      HEIGHT = 9.3
             X = 43           Y = 4.95
             SETBACK = 0.25
                      ..                       $END OF MASHRABIAH & GLASS COMMAND

    L2-NWO-L-W3-GL      = WINDOW               $MASHRABIAH & GLASS
             GLASS-TYPE = GLASS-CLEAR
             FRAME-WIDTH = 0.50                $NARROW SCREEN
             SHADING-DIVISION = 40
             WIDTH = 4      HEIGHT = 9.3
             X = 55         Y = 4.95
             SETBACK = 0.25
                      ..                       $END OF MASHRABIAH & GLASS COMMAND

NWO-FRONT-2 = EXTERIOR-WALL
             HEIGHT = 19.8     WIDTH = 9.24
             X = 0   Y = 0   Z = 0
             AZIMUTH = 180
             SHADING-SURFACE = YES
             SHADING-DIVISIONS = 40
             CONSTRUCTION = WALL-CON2FT
             ..                              $END OF EXTERIOR WALL COMMAND

$ OPENINGS   L2-NWO-F  [W-STREET WALL]

    2-NW0-F-W1    = DOOR
             WIDTH = 2.5    HEIGHT = 4
             X = 1.75        Y = 4.95
             SETBACK = 0.25
             CONSTRUCTION = DOOR-CON1
                      ..                     $END OF DOOR COMMAND

    2-NW0-F-W2    = DOOR
             WIDTH = 2.5    HEIGHT = 4
             X = 6.23        Y = 4.95
             SETBACK = 0.25
             CONSTRUCTION = DOOR-CON1
                      ..                     $END OF DOOR COMMAND
NWO-BACK-2 = EXTERIOR-WALL
             HEIGHT = 19.8     WIDTH = 9.24
             X = 9.24   Y = 64.35   Z = 0
             AZIMUTH = 0
             SHADING-SURFACE = YES
             SHADING-DIVISIONS = 40
```

```
            CONSTRUCTION = WALL-CON2FT
            ..                                $END OF EXTERIOR WALL COMMAND

$ OPENINGS   L2-NWO-B [W-STREET WALL]

    2-NWO-B-W1    = DOOR
            WIDTH = 3.5    HEIGHT = 5
            X = 3            Y = 2
            SETBACK = 0.25
            CONSTRUCTION = DOOR-CON1
                     ..                       $END OF DOOR COMMAND

    2-NWO-B-W2    = DOOR
            WIDTH = 3.5    HEIGHT = 5
            X = 3          Y = 10.7
            SETBACK = 0.25
            CONSTRUCTION = DOOR-CON1
                     ..                       $END OF DOOR COMMAND

NWO-ROOF = POLYGON
          (0,0) (9.24,0) (4.62,4.62) (4.62,59.73) (9.24,64.35) (0,64.35) ..

NWO-CEILING-2 =   ROOF
              POLYGON =  NWO-ROOF
              X = 0   Y = 0   Z = 19.80
              AZIMUTH = 180
              TILT = 0
              SHADING-SURFACE = YES
              SHADING-DIVISIONS = 40
              CONSTRUCTION = CLNG-CONWOOD
                     ..                        $END OF ROOF COMMAND

$3***********SPECIFIC SPACE DETAILS  -  T H I R D -  Floor****************************************
$3*********************[SEO] SOUH EAST WING***********************************************

SE-3 = SPACE
        SPACE-CONDITIONS = ROOM-ACH1
        AREA = 1486
        X = 50.49  Y = 0.0  Z = 31.02
        VOLUME =  24527
                   ..                         $END OF SPACE COMMANDS

SE-FRONT-3 = EXTERIOR-WALL
            HEIGHT = 16.5              WIDTH = 23.1
            X = 0  Y = 0   Z = 0
            AZIMUTH = 180
            SHADING-SURFACE = YES
            SHADING-DIVISIONS = 40
            CONSTRUCTION = WALL-CON2FT
            ..                                $END OF EXTERIOR WALL COMMAND

SE-RIGHT-3 = EXTERIOR-WALL
            HEIGHT = 16.5    WIDTH = 64.35
            X = 23.1  Y = 0   Z = 0
            AZIMUTH = 90
            SHADING-SURFACE = YES
            SHADING-DIVISIONS = 40
            CONSTRUCTION = WALL-CON2FT
            ..                                $END OF EXTERIOR WALL COMMAND

SE-BACK-3  = EXTERIOR-WALL
            HEIGHT = 16.5             WIDTH = 16.5
            X = 23.1   Y = 64.35   Z = 0
            AZIMUTH = 0
            SHADING-SURFACE = YES
            SHADING-DIVISIONS = 40
            CONSTRUCTION = WALL-CON1FT
```

```
            ..                                $END OF EXTERIOR WALL COMMAND


$ OPENINGS   L3-SE-B    [SUMMER HALL]

    3-SE-B-W1-GL   = WINDOW                   $GLASS-CLEAR
            GLASS-TYPE = GLASS-CLEAR
            SHADING-DIVISION = 40
            WIDTH = 2.7      HEIGHT = 4.8
            X = 4.5         Y = 9.5
            SETBACK = 0.7
                     ..                       $END OF GLASS-CLEAR COMMAND

    3-SE-B-W2-GL   = WINDOW                   $GLASS-CLEAR
            GLASS-TYPE = GLASS-CLEAR
            SHADING-DIVISION = 40
            WIDTH = 2.7     HEIGHT = 4.8
            X = 8.5          Y = 9.5
            SETBACK = 0.7
                     ..                       $END OF GLASS-CLEAR COMMAND



SE-LEFT1-INT-3 = INTERIOR-WALL
            HEIGHT = 16.5   WIDTH = 9.9
            X = 0   Y = 64.35   Z = 0
            TILT = 90
            AZIMUTH = 270
            NEXT-TO  NE-3
            CONSTRUCTION = WALL-CON.2FT
            ..                                $END OF INTERIOR WALL COMMAND

SE-LEFT2-INT-3 = INTERIOR-WALL
            HEIGHT = 16.5   WIDTH = 12
            X = 23   Y = 55     Z = 0
            TILT = 90
            AZIMUTH = 0
            NEXT-TO  NE-3
            CONSTRUCTION = WALL-CON.2FT
            ..                                $END OF INTERIOR WALL COMMAND

SE-LEFT-3 = EXTERIOR-WALL
            HEIGHT = 16.5   WIDTH =  54.45
            X = 0  Y = 54.45   Z = 0
            TILT = 90
            AZIMUTH = 270
            SHADING-SURFACE = YES
            SHADING-DIVISIONS = 40
            CONSTRUCTION = WALL-CON2FT
            ..                                $END OF EXTERIOR WALL COMMAND

$ OPENINGS   L3-SE-L [SUMMER HALL]
    3-SE-L-W1-GL    = WINDOW                 $GLASS-CLEAR
            GLASS-TYPE = GLASS-CLEAR
            SHADING-DIVISION = 40
            WIDTH = 2   HEIGHT = 4.5
            X = 13  Y = 4
            SETBACK = 0.7
                     ..                       $END OF GLASS-CLEAR COMMAND

    3-SE-L-W2-GL    = WINDOW                  $CLASS-CLEAR
            GLASS-TYPE = GLASS-CLEAR
            SHADING-DIVISION = 40
            WIDTH = 2    HEIGHT = 4.5
            X = 17.5  Y = 4
            SETBACK = 0.7
                     ..                       $END OF GLASS-CLEAR COMMAND
```

```
SE-ROOF-3 = ROOF               $ ceiling is wood  CLNG-CONWOOD
             X = 0   Y = 0   Z = 16.5
             HEIGHT= 64.4   WIDTH= 23.1
             AZIMUTH = 180  TILT = 0
               SHADING-SURFACE = YES
               SHADING-DIVISIONS = 40
             CONSTRUCTION = CLNG-CONWOOD
                      ..                       $ END OF ROOF COMMAND

$3******************[NE] NORTH EAST WING********************************************************

NE-3    = SPACE
         SPACE-CONDITIONS = ROOM-ACH15
         AREA = 1198
         X = 9.24  Y = 54.45  Z = 31.02
         VOLUME = 19765
                    ..                         $END OF SPACE COMMANDS

NE-FRONT-3 = EXTERIOR-WALL
             HEIGHT = 16.5     WIDTH = 41.25
             X = 0   Y = 0   Z = 0
             AZIMUTH = 180
             SHADING-SURFACE = YES
             SHADING-DIVISIONS = 40
             CONSTRUCTION = WALL-CON1.3FT
                   ..                          $END OF EXTERIOR WALL COMMAND

$ OPENINGS   L3-NE-F   [MAIDS ROOMS]
        3-NE-F-W1-GL    =  WINDOW                  $MASHRABIAH-OPEN
             GLASS-TYPE = GLASS-CLEAR
                      FRAME-WIDTH = 0.50        $NARROW SCREEN
             SHADING-DIVISION = 40
             WIDTH = 2.5      HEIGHT = 4
             X = 2.5         Y = 4.5
             SETBACK = 0.25
                                                          ..                         $END OF
MASHRABIAH-OPEN COMMAND


        3-NE-F-W2-GL    =  WINDOW                  $MASHRABIAH-OPEN
             GLASS-TYPE = GLASS-CLEAR
                      FRAME-WIDTH = 0.50        $NARROW SCREEN
             SHADING-DIVISION = 40
             WIDTH = 2.4     HEIGHT = 2.4
             X = 19.35        Y = 6
             SETBACK = 0.25
                      ..                        $END OF  MASHRABIAH-OPEN COMMAND

    3-NE-F-W3-GL    =   WINDOW   $MASHRABIAH & GLASS
             GLASS-TYPE = GLASS-CLEAR
                      FRAME-WIDTH = 0.50        $NARROW SCREEN
             SHADING-DIVISION = 40
             WIDTH = 4    HEIGHT = 6
             X = 35.2          Y = 2.5
             SETBACK = 0.25
                      ..         $END OF MASHRABIAH & GLASS COMMAND

 $ GYPSUM WINDOW AUGMENTED WITH COLORED GLASS

     3-NE-F-W-GP   = DOOR
             WIDTH = 3      HEIGHT = 4
             X = 36        Y = 10.5
             SETBACK = 0.25
             CONSTRUCTION = WINDOW-CON2
                      ..                       $END GYPSUM&GLASS COMMAND
```

```
NE-BACK-3 = EXTERIOR-WALL
             HEIGHT = 16.5     WIDTH = 47.85
             X = 47.85   Y = 26.4   Z = 0
             AZIMUTH = 0
             SHADING-SURFACE = YES
             SHADING-DIVISIONS = 40
             CONSTRUCTION = WALL-CON2FT
                  ..                          $END OF EXTERIOR WALL COMMAND

$ OPENINGS   L3-NE-B  [MASTER WING]
    3-NE-B-W1    = DOOR
             WIDTH = 2      HEIGHT = 3
             X = 31           Y = 5
             SETBACK = 0.5
             CONSTRUCTION = DOOR-CON1
                      ..                      $END OF DOOR COMMAND

    3-NE-B-W2   = DOOR
             WIDTH = 2     HEIGHT = 3
             X = 40            Y = 5
             SETBACK = 0.5
             CONSTRUCTION = DOOR-CON1
                      ..                      $END OF DOOR COMMAND

NE-RIGHT-3 = EXTERIOR-WALL
             HEIGHT = 16.5     WIDTH = 16.5
             X = 47.85   Y = 9.9   Z = 0
             AZIMUTH = 90
             SHADING-SURFACE = YES
             SHADING-DIVISIONS = 40
             CONSTRUCTION = WALL-CON1.3FT
                  ..                          $END OF EXTERIOR WALL COMMAND

NE-LEFT-3 = EXTERIOR-WALL
             HEIGHT = 16.5     WIDTH = 26.4
             X = 0   Y = 26.4   Z = 0
             AZIMUTH = 270
             SHADING-SURFACE = YES
             SHADING-DIVISIONS = 40
             CONSTRUCTION = WALL-CON1.3FT
             ..                               $END OF EXTERIOR WALL COMMAND

$ OPENINGS   L3-NE-L    [MASTER WING]

    3-NE-L-W   = DOOR
             WIDTH = 4    HEIGHT = 4
             X = 10            Y = 4.5
             SETBACK = 0.5
             CONSTRUCTION = DOOR-CON1
                      ..                      $END OF DOOR COMMAND

NE-ROOF-31   =   ROOF
            X = 0   Y = 0   Z = 16.5
            HEIGHT= 26.4  WIDTH= 41.25
            AZIMUTH = 180  TILT = 0
               SHADING-SURFACE = YES
               SHADING-DIVISIONS = 40
            CONSTRUCTION = CLNG-CONWOOD
                      ..                       $END OF ROOF COMMAND

NE-ROOF-32   =   ROOF
            X = 41.25   Y = 9.9   Z = 16.5
            HEIGHT=  16.5        WIDTH= 6.6
            AZIMUTH = 180  TILT = 0
               SHADING-SURFACE = YES
               SHADING-DIVISIONS = 40
            CONSTRUCTION = CLNG-CONWOOD
```

```
                      ..                       $END OF ROOF COMMAND

$ IIIIIIIIIIIIIIIIIIIII   I N W A R D   Z O N E S   IIIIIIIIIIIIIIIIIIIIIIIIIII

$111-IIIIIIIIIIIIIIIIIIIIIIIII [SW] SOUH WEST WING IIIIIIIIIIIIIIIIIIIIIIIIIIII

SWI-1  = SPACE
         SPACE-CONDITIONS = ROOM-ACH15
         AREA = 544.5
         X = 9.24  Y = 0.0  Z = -2.97
         VOLUME = 7726.46
                   ..                          $END OF SPACE COMMANDS

SWI-BACK-1   = EXTERIOR-WALL                   $COURTYARD WALL
             HEIGHT = 14.19      WIDTH = 41.25
             X = 41.25  Y = 13.2   Z = 0.00
             AZIMUTH = 0
             SHADING-SURFACE = YES
             SHADING-DIVISIONS = 40
             CONSTRUCTION = WALL-CON2FT
                      ..                        $END OF EXTERIOR WALL COMMAND

$ OPENINGS   L1-SWI-B  [ENTRANCE]
    1-SWI-B-D    = DOOR
             WIDTH = 6    HEIGHT = 8.3
             X = 2  Y = 0
             SETBACK = 0.25
             CONSTRUCTION = DOOR-CON1
                      ..                        $END OF DOOR COMMAND

   1-SWI-B-W1-GL    = WINDOW                    $MASHRABIAH-OPEN - ENTRY
             GLASS-TYPE = GLASS-CLEAR
             FRAME-WIDTH = 0.34                           $WIDE SCREEN
             SHADING-DIVISION = 40
             WIDTH = 3.3    HEIGHT = 4.3
             X = 15  Y = 4
             SETBACK = 0.25
                      ..                        $END OF MASHRABIAH-OPEN COMMAND

   1-SWI-B-W2-GL    = WINDOW                    $IN PLACE OF THE KITCHEN WINDOW
             GLASS-TYPE = GLASS-CLEAR
             FRAME-WIDTH = 0.34                           $WIDE SCREEN
             SHADING-DIVISION = 40
             WIDTH = 5.6    HEIGHT = 7
             X = 25  Y = 4
             SETBACK = 0.25
                      ..                        $END OF MASHRABIAH-OPEN COMMAND

   1-SWI-B-W3-GL    = WINDOW                    $IN PLACE OF THE KITCHEN WINDOW
             GLASS-TYPE = GLASS-CLEAR
             FRAME-WIDTH = 0.34                           $WIDE SCREEN
             SHADING-DIVISION = 40
             WIDTH = 3    HEIGHT = 4.3
             X = 10  Y = 6.7
             SETBACK = 0.25
                      ..                        $END OF MASHRABIAH-OPEN COMMAND

SWI-RIGHT-1 = INTERIOR-WALL
           HEIGHT = 14.19    WIDTH =  6.6
           NEXT-TO  SEI-1
           TILT = 90
           CONSTRUCTION = WALL-CON1.3FT
           X = 41.25       Y = 6.6        Z = 0
           AZIMUTH = 90
                    ..                          $END OF INTERIOR WALL COMMAND

SWI-LEFT-1 = INTERIOR-WALL
```

```
          HEIGHT = 14.19          WIDTH =  6.6
          NEXT-TO  NWI-1
          TILT = 90
          CONSTRUCTION = WALL-CON1.3FT
          X = 0           Y = 13.2          Z = 0
          AZIMUTH = 270
                ..                         $END OF INTERIOR WALL COMMAND

SWI-FLOOR-1  = UNDERGROUND-FLOOR
               X = 0   Y = 6.6   Z = 0
               AREA = 544.5
                    TILT = 0
                    U-EFFECTIVE = 0.167
               CONSTRUCTION = SWI-FLOOR-1-CON
                      ..

SWI-CEILING-1 = INTERIOR-WALL
                     X = 0   Y = 6.6   Z = 14.19
                     AREA = 544.5
                     TILT = 0
                     NEXT-TO  SWI-L2  $CEILING IS NEXT TO TERRACE & ROOM-CHECK
                CONSTRUCTION = CLNG-CONVAULT
                      ..                         $ END OF CEILING COMMAND


$111-IIIIIIIIIIIIIIIIIIIIIIIII [SE] SOUH EAST WING IIIIIIIIIIIIIIIIIIIIIIIIIIII

SEI-1 = SPACE
         SPACE-CONDITIONS = ROOM-ACH15
         AREA = 660.89
         X = 50.49  Y = 0.0  Z= -2.97
         VOLUME = 9377.98
                    ..                           $END OF SPACE COMMANDS

SEI-LEFT-1 = EXTERIOR-WALL                       $COURTYARD WALL
            HEIGHT = 14.19            WIDTH = 41.25
            X = 0    Y = 54.45   Z = 0
             AZIMUTH = 270
             SHADING-SURFACE = YES
             SHADING-DIVISIONS = 40
             CONSTRUCTION = WALL-CON3FT
             ..                                  $END OF EXTERIOR WALL COMMAND

$ OPENINGS   L1-SEI-L   [RECEPTION HALL]

    1-SEI-L-D1      = DOOR
             WIDTH = 3.3    HEIGHT = 7.92
             X = 23     Y = 0.0
             SETBACK = 0.25
             CONSTRUCTION = DOOR-CON1
                      ..                         $END OF DOOR COMMAND

    1-SEI-L-W-GL      =  WINDOW                  $MASHRABIAH-OPEN
             GLASS-TYPE = GLASS-CLEAR
                      FRAME-WIDTH = 0.34          $WIDE SCREEN
             SHADING-DIVISION = 40
             WIDTH = 7.5   HEIGHT = 9.9
             X = 12.5  Y = 1.65
             SETBACK = 0.0
                      ..                         $END OF MASHRABIAH-OPEN COMMAND

   1-SEI-L-D2      = DOOR
             WIDTH = 3.3    HEIGHT = 7.92
             X = 2    Y = 0
             SETBACK = 0.25
            CONSTRUCTION = DOOR-CON1
                      ..
```

```
SEI-BACK1 = INTERIOR-WALL
           HEIGHT = 14.19           WIDTH =  6.6
           NEXT-TO  NEI-1
           TILT = 90
           CONSTRUCTION = WALL-CON3FT
           X = 6.6        Y = 64.35         Z = 0
           AZIMUTH = 0
                    ..                        $END OF INTERIOR WALL COMMAND

SEI-LEFT-11 = INTERIOR-WALL
           HEIGHT = 14.19          WIDTH =  9.9
           NEXT-TO  NEI-1
           TILT = 90
           CONSTRUCTION = WALL-CON3FT
           X = 0.0      Y = 54.45         Z = 0
           AZIMUTH = 90
                    ..

SEI-FLOOR1 = UNDERGROUND-FLOOR
           X = 0   Y = 6.6   Z = 0.00
           AZIMUTH = 180
           AREA = 660.89
           U-EFFECTIVE = 0.069
           CONSTRUCTION = SEI-FLOOR1-1-CON
           TILT = 0
                     ..                       $END OF UNDERFGROUND FLOOR COMMAND

SEI-TOP11 = INTERIOR-WALL                       $0.25% of ceiling is limestone vault
           AREA = 165
           X = 0   Y = 6.6   Z = 14.19
           AZIMUTH = 180
           NEXT-TO SEI-2
           TILT = 0
           CONSTRUCTION = CLNG-CONVAULT
                      ..                      $ END OF CEILING COMMAND

SEI-TOP22 = INTERIOR-WALL                        $0.75 percent is wood  CLNG-CONWOOD
           AREA = 496
           X = 0   Y = 20.625   Z = 14.19
           AZIMUTH = 180
           NEXT-TO SEI-2
           TILT = 0
           CONSTRUCTION = CLNG-CONWOOD   $ WOOD CEILING
                ..                       $ END OF CEILING COMMAND

$1**INTERIOR-ZONE ********[NE] NORTH EAST WING*********************************

NEI-1 = SPACE
         SPACE-CONDITIONS = ROOM-ACH1
         AREA = 561
         X = 9.24  Y = 54.45  Z = -2.97
         VOLUME = 7958
                    ..                        $END OF SPACE COMMANDS

NEI-FRONT-1 = EXTERIOR-WALL                   $COURTYARD WALL
             HEIGHT = 14.19   WIDTH = 41.25
             X = 0   Y = 0    Z = 0
             AZIMUTH = 180
             SHADING-SURFACE = YES
             SHADING-DIVISIONS = 40
             CONSTRUCTION = WALL-CON3FT
                    ..                        $END OF EXTERIOR WALL COMMAND

$ OPENINGS   L1-NEI-F  [PANTRY]
    3-NEI-F-W1    = DOOR
             WIDTH = 3.3      HEIGHT = 3.96
```

```
            X = 4.95        Y = 5.61
            SETBACK = 0.25
            CONSTRUCTION = DOOR-CON1
                     ..                        $END OF DOOR COMMAND

    3-NEI-F-D1    = DOOR
            WIDTH = 4.95     HEIGHT = 7.92
            X = 11           Y = 0.00
            SETBACK = 0.25
            CONSTRUCTION = DOOR-CON1
                     ..                        $END OF DOOR COMMAND

    3-NEI-F-D2    = DOOR
            WIDTH = 4.95     HEIGHT = 7.92
            X = 19           Y =0.00
            SETBACK = 0.25
            CONSTRUCTION = DOOR-CON1
                     ..                        $END OF DOOR COMMAND

    3-NEI-F-W2    = DOOR
            WIDTH = 3.3      HEIGHT = 3.96
            X = 26           Y = 5.61
            SETBACK = 0.25
            CONSTRUCTION = DOOR-CON1
                     ..

NEI-LEFT-1 = INTERIOR-WALL
          HEIGHT = 14.19     WIDTH =  9.9
          NEXT-TO  NWI-1
          TILT = 90
          CONSTRUCTION = WALL-CON.2FT
          X = 0.0       Y = 9.9        Z = 0
          AZIMUTH = 270
                    ..                         $END OF INTERIOR WALL COMMAND

NEI-FLOOR1-1= UNDERGROUND-FLOOR
          X = 0   Y = 0   Z = 0
          AZIMUTH = 180
          AREA = 561
          U-EFFECTIVE = 0.081
          CONSTRUCTION = NEI-FLOOR1-1-CON
          TILT = 0
                     ..                       $END OF UNDERFGROUND FLOOR COMMAND

NEI-TOP1-1 = INTERIOR-WALL
          AREA = 561
          X = 0   Y = 0   Z = 14.19
          NEXT-TO  NEI-2
          AZIMUTH = 180
          CONSTRUCTION = WALL-CON1.3FT
          TILT = 0
                     ..                        $ END OF CEILING COMMAND

$1**INTERIOR-ZONE ******[NW] NORTH WEST WING*********************************************

NWI-1 = SPACE
         SPACE-CONDITIONS = ROOM-ACH1
         AREA = 261
         X = 0  Y = 0  Z = -2.97
         VOLUME = 3710
                    ..                         $END OF SPACE COMMANDS

NWI-RIGHT-1 = EXTERIOR-WALL                    $COURTYARD WALL
            HEIGHT = 14.19          WIDTH = 41.25
            X = 9.24   Y = 13.2   Z = 0
            AZIMUTH = 90
            SHADING-SURFACE = YES
```

```
             SHADING-DIVISIONS = 40
             CONSTRUCTION = WALL-CON2FT
             ..                                  $END OF EXTERIOR WALL COMMAND

$ OPENINGS   L1-NWI-R  [STAIRS WING]
    1-NWI-R-D    = DOOR
             WIDTH = 3.3    HEIGHT = 6.6
             X = 31.5  Y = 2
             SETBACK = 0.25
            CONSTRUCTION = DOOR-CON1
                      ..                         $END OF DOOR COMMAND



NWI-FLOOR-1 = UNDERGROUND-FLOOR
           X = 0   Y = 0   Z = 0.00
           AZIMUTH = 180
           AREA = 261
           U-EFFECTIVE =  0.174
           CONSTRUCTION = NWI-FLOOR-1-CON
           TILT = 0
                     ..                          $END OF UNDERFGROUND FLOOR COMMAND

NWI-TOP-1 = INTERIOR-WALL
           AREA = 261
           X = 0   Y = 0   Z = 14.19
           NEXT-TO  NWI-2
           AZIMUTH = 180
           TILT = 0
           CONSTRUCTION = CLNG-CONWOOD
                      ..                         $ END OF CEILING COMMAND
$
$
$
$2**INTERIOR-ZONE************[SW] SOUH WEST ROOM**************************************

SWI-R2  = SPACE
         SPACE-CONDITIONS = ROOM-ACH1
         AREA = 120
         X = 35.64   Y = 0.0   Z = 11.22
         VOLUME = 2372
                    ..                         $END OF SPACE COMMANDS

SWIR-RIGHT-2 = INTERIOR-WALL
           HEIGHT = 19.80    WIDTH =  6.6
           NEXT-TO  SEI-2
           TILT = 90
           CONSTRUCTION = WALL-CON2
           X = 14.85       Y = 6.6        Z = 0
           AZIMUTH = 90
                    ..                           $END OF INTERIOR WALL COMMAND

SWIR-LEFT-2 = EXTERIOR-WALL           $COURTYARD WALL AND TERRACE WALL
                    HEIGHT = 19.80     WIDTH = 13.2
 $                  NEXT-TO  SWI-L2  when it was an interior wall
                    TILT = 90
                    X = 0.0    Y = 13.2    Z = 0
                    AZIMUTH = 270
                    SHADING-SURFACE = YES
                    SHADING-DIVISIONS = 40
                    CONSTRUCTION = WALL-CON2FT
                                ..                           $END OF EXERIOR WALL

SWIR-BACK-2 = EXTERIOR-WALL            $COURTYARD WALL
             HEIGHT = 19.80   WIDTH = 14.85
             X = 14.85   Y = 13.2    Z = 0
             AZIMUTH = 0
```

```
            SHADING-SURFACE = YES
            SHADING-DIVISIONS = 40
            CONSTRUCTION = WALL-CON2FT
                   ..                          $END OF EXTERIOR WALL COMMAND

   $ OPENINGS   L2-SWIR-B  [ABOVE ENTRACE]

   2-SWIR-B-W1-GL    =  WINDOW                $IN PLACE OF THE G-HALL BACK WINDOW
            GLASS-TYPE = GLASS-CLEAR
            FRAME-WIDTH = 0.50                         $NARROW SCREEN
            SHADING-DIVISION = 40
            WIDTH = 4.6    HEIGHT = 6
            X = 1.5  Y = 2.5
            SETBACK = 0.0
                   ..                         $END OF    MASHRABIAH & GLASS COMMAND

   2-SWIR-B-W2-GL    = WINDOW                 $IN PLACE OF THE G-HALL BACK WINDOW
            GLASS-TYPE = GLASS-CLEAR
            FRAME-WIDTH = 0.50                          $NARROW SCREEN
            SHADING-DIVISION = 40
            WIDTH = 4.6    HEIGHT = 6
            X = 7  Y = 2.5
            SETBACK = 0.0
                   ..                           $END OF    MASHRABIAH & GLASS COMMAND

SWI-ROOF = POLYGON
           (0,0) (6.6,6.6) (14.85,6.6) (14.85,13.2) (0,13.2)..

SWI-CEILING-R =   ROOF
              POLYGON =  SWI-ROOF
              X = 0   Y = 0   Z = 19.80
              AZIMUTH = 180
              TILT = 0
              SHADING-SURFACE = YES
              SHADING-DIVISIONS = 40
              CONSTRUCTION = CLNG-CONWOOD
                    ..                         $END OF ROOF COMMAND

$2**INTERIOR-ZONE**** TERRACE ********[SW] SOUH WEST TERRACE**********************************
$2**INTERIOR-ZONE**** TERRACE ********[SW] SOUH WEST TERRACE**********************************

SWI-L2  = SPACE                                $TERRACE
         SPACE-CONDITIONS = ROOM-ACH1          $SHOULD THIS BE CHANGED SINCE IT IS A TERRACE?
         AREA = 348
         X = 9.24  Y = 0.0  Z = 11.22
         VOLUME = 6900
                  ..                          $END OF SPACE COMMANDS

$SWIL-ADIAB-2 = INTERIOR-WALL      CHANGED TO BE EXTERIOR WALL TO HAVE ITS SHADING EFFECT
$              HEIGHT = 19.80   WIDTH = 26.4
$              INT-WALL-TYPE = ADIABATIC
$              TILT = 90
$              X = 0         Y = 0         Z = 0
$              AZIMUTH = 180
$              CONSTRUCTION = WALL-CON2
$                     ..  END OF ADIABATIC INTERIOR WALL COMMAND  [USED AS ADIABATIC EXTERIOR]

SWIL-FRONT-2 = EXTERIOR-WALL           $COURTYARD WALL & TERRACE EXT WALL
             HEIGHT = 19.80   WIDTH = 26.4
              TILT = 90
             X = 0           Y = 0         Z = 0
             AZIMUTH = 180
            SHADING-SURFACE = YES
            SHADING-DIVISIONS = 40
            CONSTRUCTION = WALL-CON2FT
            ..                                 $END OF EXTERIOR WALL COMMAND
```

```
$ OPENINGS  SWIL-ADIAB-2 [ABOVE ENTRY-DOOR]THREE SMALL OPENINGS-WINDOWS NEED TO BE ON
$ EXTERNAL WALL ONLY, ADIABATIC WALL NEED TO HAVE NO WINDOWS

     2-SWIL-AD-W1   = DOOR
             WIDTH = 2      HEIGHT = 3
             X = 2            Y = 6
             SETBACK = 0.25
             CONSTRUCTION = DOOR-CON1
                     ..                       $END OF DOOR COMMAND

     2-SWIL-AD-W2   = DOOR
             WIDTH = 2      HEIGHT = 3
             X = 6            Y = 6
             SETBACK = 0.25
             CONSTRUCTION = DOOR-CON1
                      ..                      $END OF DOOR COMMAND

     2-SWIL-AD-W3   = DOOR
             WIDTH = 2      HEIGHT = 3
             X = 10         Y = 6
             SETBACK = 0.25
             CONSTRUCTION = DOOR-CON1
                      ..                      $END OF DOOR COMMAND

$SWIL-CEILING-2 =   INTERIOR-WALL         SHOULD THIS BE EXTERIOR WALL [ROOF]?
$              X = 0   Y = 0   Z = 19.80
$              INT-WALL-TYPE = ADIABATIC
$              AREA = 348
$              TILT = 0
$               SHADING-SURFACE = YES
$               SHADING-DIVISIONS = 40
$              CONSTRUCTION = CLNG-CONVAULT
$                      ..                        END OF ADIABATIC CEILING COMMAND

SWIL-CEILING-2 =   ROOF         $ROOF OR COULD BE SHADE
             X = 0   Y = 0   Z = 19.80
             HEIGHT= 13.2   WIDTH= 26.4
             AZIMUTH = 180  TILT = 0
               SHADING-SURFACE = YES
               SHADING-DIVISIONS = 40
             CONSTRUCTION = CLNG-CONWOOD
             ..                          $END OF ROOF COMMAND


$2**INTERIOR-ZONE*****[SE] SOUTH EAST WING*******************************************

SEI-2 = SPACE
         SPACE-CONDITIONS = ROOM-ACH1
         AREA = 660.89
         X = 50.49  Y = 0.0  Z= 11.22
         VOLUME = 13086
                    ..                         $END OF SPACE COMMANDS

SEI-LEFT-2 = EXTERIOR-WALL                     $COURTYARD WALL
             HEIGHT = 19.80          WIDTH = 41.25
             X = 0    Y = 54.45   Z = 0
             AZIMUTH = 270
             SHADING-SURFACE = YES
             SHADING-DIVISIONS = 40
             CONSTRUCTION = WALL-CON2.5FT
             ..                                $END OF EXTERIOR WALL COMMAND

$ OPENINGS   L2-SEI-L [SUMMER HALL]
    2-SEI-L-W-GL    = WINDOW                   $MASHRABIAH & GLASS
             GLASS-TYPE = GLASS-CLEAR
             FRAME-WIDTH = 0.50        $NARROW SCREEN
             SHADING-DIVISION = 40
```

```
             WIDTH = 12.5   HEIGHT = 10
             X = 10  Y = 4
             SETBACK = 0.0
                      ..                      $END OF MASHRABIAH & GLASS COMMAND

SEI-BACK2 = INTERIOR-WALL
           HEIGHT = 19.80           WIDTH =  6.6
           NEXT-TO  NEI-2
           TILT = 90
           CONSTRUCTION = WALL-CON1FT
           X = 6.6        Y = 64.35         Z = 0
           AZIMUTH = 0
             ..                        $END OF INTERIOR WALL COMMAND

SEI-LEFT-21 = INTERIOR-WALL
           HEIGHT = 19.80          WIDTH =  9.9
           NEXT-TO  NEI-2
           TILT = 90
           CONSTRUCTION = WALL-CON.75FT
           X = 0.0      Y = 54.45         Z = 0
           AZIMUTH = 90
                    ..

SEI-TOP2 = INTERIOR-WALL                        $100 percent is wood  CLNG-CONWOOD
           AREA = 661
           X = 0   Y = 20.625   Z = 19.80
           AZIMUTH = 180
           NEXT-TO SEI-2
           TILT = 0
           CONSTRUCTION = CLNG-CONWOOD
                ..                      $ END OF CEILING COMMAND

$2**INTERIOR-ZONE ********[NE] NORTH EAST WING****************************************

NEI-2 = SPACE
         SPACE-CONDITIONS = ROOM-ACH1
         AREA = 561
         X = 9.24  Y = 54.45  Z = 11.22
         VOLUME = 11105
                    ..                        $END OF SPACE COMMANDS

NEI-FRONT-2 = EXTERIOR-WALL                   $COURTYARD WALL
             HEIGHT = 19.80   WIDTH = 41.25
             X = 0   Y = 0    Z = 0
             AZIMUTH = 180
             SHADING-SURFACE = YES
             SHADING-DIVISIONS = 40
             CONSTRUCTION = WALL-CON1FT
                    ..                        $END OF EXTERIOR WALL COMMAND

$ OPENINGS   L2-NEI-F  [WINTER HALL]

         2-NEI-F-W1-GL    = WINDOW                        $MASHRABIAH & GLASS
             GLASS-TYPE = GLASS-CLEAR
                      FRAME-WIDTH = 0.50        $NARROW SCREEN
             SHADING-DIVISION = 40
             WIDTH = 7.5      HEIGHT = 6.5
             X = 0           Y = 3
             SETBACK = 0.0
                      ..                                  $END OF  MASHRABIAH & GLASS COMMAND

         2-NEI-F-W2-GL    = WINDOW                        $MASHRABIAH & GLASS
             GLASS-TYPE = GLASS-CLEAR
                      FRAME-WIDTH = 0.50        $NARROW SCREEN
             SHADING-DIVISION = 40
         WIDTH = 6.5     HEIGHT = 6.5
             X = 17           Y = 3
```

```
             SETBACK = 0.0
                                                                 ..                               $END OF
MASHRABIAH & GLASS COMMAND


         2-NEI-F-W3-GL    = WINDOW                         $MASHRABIAH & GLASS
             GLASS-TYPE = GLASS-CLEAR
                      FRAME-WIDTH = 0.50        $NARROW SCREEN
                        SHADING-DIVISION = 40
             WIDTH = 7.5     HEIGHT = 6.5
             X = 32            Y = 3          $X WAS 33.5
             SETBACK = 0.0
                                                                 ..                               $END OF
MASHRABIAH & GLASS COMMAND

    $ GYPSUM WINDOWS AUGMENTED WITH COLORED GLASS

     2-NEI-F-W1-GP    = DOOR
             WIDTH = 4.3      HEIGHT = 5.6
             X = 1.6        Y = 13
             SETBACK = 0.25
             CONSTRUCTION = WINDOW-CON2
                      ..                       $END OF DOOR COMMAND

     2-NEI-F-W2-GP    = DOOR
             WIDTH = 4.3      HEIGHT = 5.6
             X = 18.35       Y = 13
             SETBACK = 0.25
             CONSTRUCTION = WINDOW-CON2
                      ..                       $END OF DOOR COMMAND

      2-NEI-F-W3-GP    = DOOR
             WIDTH = 4.3      HEIGHT = 5.6
             X = 35.1         Y = 13
             SETBACK = 0.25
             CONSTRUCTION = WINDOW-CON2
                      ..                       $END OF DOOR COMMAND

NEI-LEFT-2 = INTERIOR-WALL
           HEIGHT = 19.80     WIDTH =  9.9
           NEXT-TO  NWI-2
           TILT = 90
           CONSTRUCTION = WALL-CON1FT
           X = 0.0       Y = 9.9         Z = 0
           AZIMUTH = 270
                    ..                         $END OF INTERIOR WALL COMMAND

NEI-TOP1-2 = INTERIOR-WALL
           AREA = 561
           X = 0   Y = 0   Z = 19.80
           NEXT-TO  NEI-2
           AZIMUTH = 180
           TILT = 0
           CONSTRUCTION = CLNG-CONVAULT
                      ..                       $ END OF CEILING COMMAND

$2**INTERIOR-ZONE ******[NW] NORTH WEST WING*****************************************

NWI-2 = SPACE
         SPACE-CONDITIONS = ROOM-ACH15
         AREA = 287
         X = 4.62   Y = 0  Z = 11.22
         VOLUME = 5675
                    ..                         $END OF SPACE COMMANDS

NWI-RIGHT-2 = EXTERIOR-WALL                    $COURTYARD WALL
             HEIGHT = 19.80          WIDTH = 54.45
```

```
             X = 4.62   Y = 0   Z = 0
             AZIMUTH = 90
             SHADING-SURFACE = YES
             SHADING-DIVISIONS = 40
             CONSTRUCTION = WALL-CON2FT
             ..                                 $END OF EXTERIOR WALL COMMAND

$ OPENINGS   L2-NWI-R  [STAIRS WING]
    2-NWI-R-W-GL    = WINDOW                   $MASHRABIAH-OPEN
             GLASS-TYPE = GLASS-CLEAR
             FRAME-WIDTH = 0.50                          $NARROW SCREEN
             SHADING-DIVISION = 40
             WIDTH = 1.7    HEIGHT = 2.8
             X = 32  Y = 10
             SETBACK = 0.25
                      ..                        $END OF MASHRABIAH-OPEN COMMAND

NWI-ROF-2 = POLYGON
           (0,4.62) (4.62,0) (4.62,64.35) (0,59.73)  ..

NWI-TOP-2 = ROOF
           POLYGON = NWI-ROF-2
           X = 0   Y = 0   Z = 19.80
           AZIMUTH = 180
           TILT = 0
           SHADING-SURFACE = YES
           SHADING-DIVISIONS = 40
           CONSTRUCTION = CLNG-CONWOOD
                      ..                        $ END OF ROOF COMMAND

$CY-FLOOR**INTERIOR-ZONE ******[CY] COURTYARD FLOOR SPACE
*****************************************

CY-0 = SPACE
         SPACE-CONDITIONS = ROOM-OPEN1
         AREA = 1702
         X = 9.24   Y = 13.2  Z = -2.97
         VOLUME = 1702
                    ..                          $END OF SPACE COMMANDS

NWI-FRONT-1 = EXTERIOR-WALL
             HEIGHT = 41.25          WIDTH = 41.
             X = 0   Y = 0   Z = 0
             AZIMUTH = 180
             TILT= 0
             SHADING-SURFACE = YES
             SHADING-DIVISIONS = 40
             CONSTRUCTION = FLOOR-CON2
             ..                                 $END OF EXTERIOR WALL COMMAND

NWI-FRONT-2 = EXTERIOR-WALL
             HEIGHT = 41.25          WIDTH = 0.25
             X = 41   Y = 0   Z = 0
             AZIMUTH = 180
             TILT= 0
             SHADING-SURFACE = YES
             SHADING-DIVISIONS = 40
             CONSTRUCTION = FLOOR-CON2
             ..                                 $END OF EXTERIOR WALL COMMAND
BOX-1 = SPACE
SPACE-CONDITIONS = AC-BOX
AREA=1  VOLUME = 1
SHAPE = BOX  HEIGHT= 1
WIDTH = 1  DEPTH = 1
NUMBER-OF-PEOPLE = 1  ..

FRONT-B = INTERIOR-WALL  AZIMUTH=180 AREA=1
```

```
HEIGHT=1  WIDTH=1
INT-WALL-TYPE= ADIABATIC
NEXT-TO SWO-1
CONSTRUCTION = WALL-1  ..

RIGHT-B = INTERIOR-WALL  AZIMUTH = 90 AREA=1
HEIGHT = 1 WIDTH=1
INT-WALL-TYPE= ADIABATIC
NEXT-TO SWO-1
CONSTRUCTION = WALL-1 ..

LEFT-B = INTERIOR-WALL AZIMUTH= 270 AREA=1
INT-WALL-TYPE= ADIABATIC
NEXT-TO SWO-1
CONSTRUCTION=WALL-1 ..

BACK-B = INTERIOR-WALL AZIMUTH=0 AREA=1
INT-WALL-TYPE=ADIABATIC
NEXT-TO SWO-1
CONSTRUCTION=WALL-1 ..

CEILINHG-B = INTERIOR-WALL AREA=1
TILT=0
INT-WALL-TYPE=ADIABATIC
NEXT-TO SWO-1
CONSTRUCTION=WALL-1  ..

FLOOR-B = UNDERGROUND-FLOOR  AREA = 1  CONSTRUCTION= FLOOR-1 ..

$------LOADS HOURLY REPORT-------$

SCH-1      =    SCHEDULE  THRU DEC 31 (ALL)(1,24)(1)  ..

$SOLRAD            = REPORT-BLOCK
$V-T               = GLOBAL
$V-L               = (13) ..  TOTAL HORIZONAL SOLAR RADIATION/WEATHER-FILE

$SOLAR RADIATION ON COURTRYARD NORTH-SIDE WALLS AFTER SHADING – FIRST FLOOR

NEI-EXT-1         = REPORT-BLOCK
V-T               = NEI-FRONT-1
V-L               = (1) .. $ SOLAR RADIATION ON NEI-1 COURTYARD WALL AFTER SHADING -BTU/HR

NWI-EXT-1         = REPORT-BLOCK
V-T               = NWI-RIGHT-1
V-L               = (1) .. $ SOLAR RADIATION ON NWI-1 COURTYARD WALL AFTER SHADING -BTU/HR

NEI-EXT-2         = REPORT-BLOCK
V-T               = NEI-FRONT-2
V-L               = (1) .. $ SOLAR RADIATION ON NEI-2 COURTYARD WALL AFTER SHADING -BTU/HR

NWI-EXT-2         = REPORT-BLOCK
V-T               = NWI-RIGHT-2
V-L               = (1) .. $ SOLAR RADIATION ON NWI-2 COURTYARD WALL AFTER SHADING -BTU/HR

$SOLAR RADIATION ON COURTYARD SOUTH-SIDE WALLS AFTER SHADING – SECOND FLOOR

SEI-EXT-1         = REPORT-BLOCK
V-T               = SEI-LEFT-1
V-L               = (1) .. $ SOLAR RADIATION ON SEI-1 COURTYARD WALL AFTER SHADING -BTU/HR

SWI-EXT-1         = REPORT-BLOCK
V-T               = SWI-BACK-1
V-L               = (1) .. $ SOLAR RADIATION ON SWI-1 COURTYARD WALL AFTER SHADING -BTU/HR

SEI-EXT-2         = REPORT-BLOCK
V-T               = SEI-LEFT-2
```

```
V-L               = (1) .. $ SOLAR RADIATION ON SEI-2 COURTYARD WALL AFTER SHADING -BTU/HR

SWI-EXT-2         = REPORT-BLOCK
V-T               = SWIR-BACK-2
V-L               = (1) .. $ SOLAR RADIATION ON SWI-R2 COURTYARD WALL AFTER SHADING -BTU/HR

$SOLAR RADIATION ON COURTYARD SOUTH-SIDE WALLS AFTER SHADING – SECOND FLOOR

CY-FLOOR          = REPORT-BLOCK
V-T               = NWI-FRONT-1
V-L               = (1) .. $ SOLAR RADIATION ON NWI-FRONT-0 COURTYARD FLOOR AFTER SHADING -BTU/HR

$SOLAR RADIATION ON THE HOUSE EXTERNAL SOUTH-SIDE WALLS AFTER SHADING – SECOND FLOOR [IF-NEEDED]

$SOLAR RADIATION ON THE HOUSE EXTERNAL NORTH-SIDE WALLS AFTER SHADING – SECOND FLOOR [IF-NEEDED]

LDS-REP-1 = HOURLY-REPORT   REPORT-SCHEDULE=SCH-1
REPORT-BLOCK=(NEI-EXT-1,NWI-EXT-1,NEI-EXT-2,NWI-EXT-2,SEI-EXT-1,SWI-EXT-1,
SEI-EXT-2,SWI-EXT-2,CY-FLOOR)..
END  ..
COMPUTE  LOADS   ..

$*********STSTEMS*******************************************************************

INPUT SYSTEMS ..
SYSTEMS-REPORT     SUMMARY = (SS-A)  ..         $REPORTS TO BE PRINTED
$                SS-A,                           SYSTEM MONTHLY LOADS SUMMARY

$ SCHEDULES

HEAT-1 = SCHEDULE  THRU DEC 31 (ALL) (1,24) (45)..

COOL-1 = SCHEDULE  THRU DEC 31 (ALL) (1,24) (120)..

NOVENT-1 = SCHEDULE  THRU DEC 31 (ALL) (1,24) (0)..

DAYVENT-1 = SCHEDULE  THRU DEC 31 (ALL) (1,5) (0) (6,18)(1) (19,24) (0) ..

NIGHTVENT-2 = SCHEDULE  THRU DEC 31 (ALL) (1,5) (1) (6,18)(0) (19,24) (1) ..

$ ZONE DATA

BOX-1   = ZONE   DESIGN-HEAT-T=50
                 DESIGN-COOL-T=100
                 ZONE-TYPE=CONDITIONED
                 THERMOSTAT-TYPE=TWO-POSITION
                 HEAT-TEMP-SCH=HEAT-1
                 COOL-TEMP-SCH=COOL-1  ..

SWO-1  = ZONE      ZONE-TYPE = UNCONDITIONED ..
SEO-1  = ZONE      ZONE-TYPE = UNCONDITIONED ..
NEO-1  = ZONE      ZONE-TYPE = UNCONDITIONED ..
NWO-1  = ZONE      ZONE-TYPE = UNCONDITIONED ..
SWO-R2 = ZONE      ZONE-TYPE = UNCONDITIONED ..
SEO-2  = ZONE      ZONE-TYPE = UNCONDITIONED ..
NEO-2  = ZONE      ZONE-TYPE = UNCONDITIONED ..
NWO-2  = ZONE      ZONE-TYPE = UNCONDITIONED ..
SE-3   = ZONE      ZONE-TYPE = UNCONDITIONED ..
NE-3   = ZONE      ZONE-TYPE = UNCONDITIONED ..
SWI-1  = ZONE      ZONE-TYPE = UNCONDITIONED ..
SEI-1  = ZONE      ZONE-TYPE = UNCONDITIONED ..
NEI-1  = ZONE      ZONE-TYPE = UNCONDITIONED ..
NWI-1  = ZONE      ZONE-TYPE = UNCONDITIONED ..
SWI-R2 = ZONE      ZONE-TYPE = UNCONDITIONED ..
SWI-L2 = ZONE      ZONE-TYPE = UNCONDITIONED ..
SEI-2  = ZONE      ZONE-TYPE = UNCONDITIONED ..
NEI-2  = ZONE      ZONE-TYPE = UNCONDITIONED ..
```

```
NWI-2  = ZONE      ZONE-TYPE = UNCONDITIONED ..
CY-0   = ZONE      ZONE-TYPE = UNCONDITIONED ..
$END OF ZONE COMMANDS

$AIR CONDITIONER

SYS-1  = SYSTEM     SYSTEM-TYPE=RESYS
                    ZONE-NAMES=(BOX-1, SWO-1,SEO-1,
                    NEO-1, NWO-1, SWO-R2,SEO-2,NEO-2,
                    NWO-2, SE-3, NE-3, SWI-1, SEI-1,
                    NEI-1, NWI-1, SWI-R2, SWI-L2,
                    SEI-2, NEI-2, NWI-2,CY-0)
                    MAX-SUPPLY-T=140 MIN-SUPPLY-T=50
                    NATURAL-VENT-AC=20
                    NATURAL-VENT-SCH=DAYVENT-1  ..

PLANT-1  = PLANT-ASSIGNMENT SYSTEM-NAMES=(SYS-1)  ..

$------SYSTEM HOURLY REPORT-------$

HR-SCH-1          =SCHEDULE    THRU DEC 31 (ALL)(1,24)(1)  ..

HR-SCH-2          =SCHEDULE    THRU JAN 16 (ALL)(1,24)(0)
                               THRU JAN 22 (ALL)(1,24)(1)
                               THRU DEC 31 (ALL)(1,24)(0)  ..

$ REPORT BLOCK

SRB-1   = REPORT-BLOCK    VARIABLE-TYPE = SEI-1
          VARIABLE-LIST = (6,31,92)  ..
          $ZONE TEMP, AVERAGE TEMP, OT

$SRB-4   = REPORT-BLOCK    VARIABLE-TYPE = BOX-1
$          VARIABLE-LIST = (6,9,31,8,91,92)  ..
          $ZONE TEMP, THERMAL CONDUCTANCE
          $AVERAGE TEMP, TOTAL ZONE COOLING ENREGY INPUT
          $MRT, OT

REP1 = HOURLY-REPORT  REPORT-SCHEDULE = HR-SCH-1  REPORT-BLOCK = (SRB-1) ..

END  ..
COMPUTE SYSTEMS ..
STOP  ..
```

APPENDIX E

CORRESPONDENCE WITH ENERGYPLUS SUPPORT

On 23 Jul 2003, at 10:10, Amr A. Bagneid wrote:
>
> > Hello,
> >
> > MY question is:
> >
> > The courtyard inside a building is a semi-open space which have its own
> > microclimate that differs from ambient climate. When simulating a
> > courtyard building in EnergyPlus, can it generate the microclimate
> > inside the courtyard.
> >
> > Thank you and I am looking forward to receive your reply soon.
> >
> > Amr Bagneid
> > Ph.D. program
> > Texas A&M University
> >

----- Original Message -----
From: "Michael J. Witte" <mjwitte@gard.com>
To: <amr>
Sent: Wednesday, July 30, 2003 4:36 PM
Subject: Re: Courtyard microclimate

> The simplest approach is to set the walls which are exposed to the
> courtyard to use the NoWind flag. The only other way to do this
> would be to make the courtyard be a separate zone, but you would need
> to describe windows on the top of the courtyard to let solar gains
> enter it and interior windows between the courtyard and the adjacent
> spaces in order to let solar gains into the conditioned zones. You
> would also need to define some value of infiltration to exchange air
> between the courtyard and the ambient. If you proceed with this
> approach, you should run sensitivities on various parts of the
> courtyard assumptions to determine which values are most influential
> on the answer.
>
> Mike
>
>

APPENDIX F

INVENTORY OF THE CASE STUDY HOUSE MASS

Ground floor

SW wing: Entry hall, porter room, storage room

		int.walls	External walls				ceiling	floors		Courtyard walls		
int/ext wall-courtyard										Main	Kit.	Serv.
Spaces		SW	SW	SW	SW		SW	SW		SW		
Material		Stone	Stone	Stone	Stone	Soil	Wood	Stone	Soil	Stone	Stone	Stone
Bulk Density	lb/ft3	103	103	103	103	91	85	103	91	103	103	103
Orientation			S	W	UG	UG			UG	S	S	S
volume	ft3	1722	1189	261	384	171	504	504	1008	987	478	194
MASS	lb	177344	122419	26895	39524	15561	42841	51912	91728	101652	49262	20018
Sum	lb	177344		204399			42841	143640		170932		
Total Int.walls+ceiling+floor	lb			433104								
Total ceiling+floor, ext.& int.walls+courtyard(except main court)	lb			808436								
			Bulk int. mass density (weighted to mass) =						82	Density=		103

SE wing: Entry-porter room-Reception hall, reception room-kitchen

		int.walls	External walls					ceiling		floors		Courtyard walls		
int/ext wall-courtyard												Main	Kit.	Serv.
Spaces		SE	SE	SE	SE	SE		SE	SE	SE		SE		
Material		Stone	Stone	Stone	Stone	Stone	Soil	Wood	Stone	Stone	Soil	Stone	Stone	Stone
Bulk Density	lb/ft3	103	103	103	103	103	91	85	103	103	91	103	103	103
Orientation			S	E	N	UG	UG				UG	E	E-ext.	E-ext.
volume	ft3	4446	1285	1143	360	738	336	1096	491	1707	3414	1366	474	547
MASS	lb	457904	132312	117720	37097	76005	30576	93137	50587	175811	310656	140749	48793	56300
Sum	lb	457904		393709				143724		486466		245842		
Total Int.walls+ceiling+floor	lb			1193187										
Total ceiling+floor, ext.& int.walls+courtyard(except main court)	lb			1832738										
			Bulk int. mass density (weighted to mass) =						89			Density=		103

NE wing: Kitchen, pantry rooms, WC

		int.walls	External walls				ceiling		floors		Courtyard walls		
int/ext wall-courtyard											Main	Kit.	Serv.
Spaces		NE	NE	NE	NE	NE	NE	NE	NE		NE		
Material		Stone	Stone	Stone	Stone	Soil	Wood	Stone	Stone	Soil	Stone	Stone	Stone
Bulk Density	lb/ft3	103	103	103	103	91	85	103	103	91	103	103	103
Orientation			N	W	UG	UG				UG			N-ext.
volume	ft3	1526	654	375	272	158		686	686	1372	1291	128	670
MASS	lb	157170	67330	38581	28035	14378		70665	70665	124865	132930	13137	68967
Sum	lb	157170		148324			70665		195530		215033		
Total Int.walls+ceiling+floor	lb			505469									
Total ceiling+floor, ext.& int.walls+courtyard(except main court)	lb			868827									
			Bulk int. mass density (weighted to mass) =					83			Density=		103

NW wing: Stairs - Storage

		int.walls	External walls					ceiling	floors		Courtyard walls		
int/ext wall-courtyard											Main	Kit.	Serv.
Spaces		NW	NW	NW	NW	NW		NW	NW		NW		
Material		Stone	Stone	Stone	Stone	Stone	Soil	Wood	Stone	Soil	Stone	Stone	Stone
Bulk Density	lb/ft3	103	103	103	103	103	91	85	103	91	103	103	103
Orientation			N	S	W	UG	UG			UG	W	W	W
volume	ft3	384	250	192	1017	386	233	171	334	669	759	711	455
MASS	lb	39566	25720	19785	104736	39770	21203	14532	34438	60852	78194	73190	46916
Sum	lb	39566		21214				14532	95290		198300		
Total Int.walls+ceiling+floor	lb			269494									
Total ceiling+floor, ext.& int.walls+courtyard(except main court)	lb			679008									
			Bulk int. mass density (weighted to mass) =						53		Density=		103

	Internal walls	exterior walls	ceiling	Floor	courtyard walls	Ground floor
Totals	831984	957647	271762	920926	830107	3812426

First Floor

SW wing: Terrace - Grand summer hall vestibule

		int.walls	External walls		ceiling	Main	Courtyard walls		
int/ext wall-courtyard							Main	Kit.	Serv.
Orientation			S	W	S	T.roof	S	S	S
volume	ft3	1422	1143	349	585	428	1144	217	262
MASS	Lb	146423	117729	35933	49724	36361	117832	22367	26950
Sum ext.walls	lb	146423		153662	49724	154193	167149		
Total Int.walls+ceiling+floor	lb		245464						
Total ceiling+floor, ext.& int.walls+courtyard(except main court)	lb		566274						
		Bulk int. mass density (weighted to mass) =			79		Density=		103

SE wing: Grand summer hall - Bath quarter

		int.walls	External walls			ceiling	ceiling		Courtyard walls		
int/ext wall-courtyard									Main	Kit.	Serv.
Orientation		INT	S	E	N					E-ext.	E-ext.
volume	ft3	2850	1751	1631	631	196	196	1542	1900	574	539
MASS	Lb	293500	180353	167993	65010	16658	20190		195700	59100	55554
Sum ext.walls	lb	293500		413356		36848			310354		
Total Int.walls+ceiling+floor	lb			445003							
Total ceiling+floor, ext.& int.walls+courtyard(except main court)	lb			1168713							
		Bulk int. mass density (weighted to mass) =				76			Density=		103

NE wing: Wiinter hall - Mezanine - stairs

		int.walls	External walls		ceiling		Courtyard walls		
int/ext wall-courtyard							Main	Kit.	Serv.
Orientation			N	W			N	N	N-ext.
volume	ft3	3036	1928	551	907	534	884	238	707
MASS	Lb	312703	198576	56736	77090		91052	24549	72811
Sum ext.walls	lb	312703		255312	77090		188413		
Total Int.walls+ceiling+floor	lb		487154						
Total ceiling+floor, ext.& int.walls+courtyard(except main court)	lb		930879						
		Bulk int. mass density (weighted to mass) =			80		Density=		103

NW wing: Stairs - W.C. - room

		int.walls	External walls			ceiling	Courtyard walls		
int/ext wall-courtyard							Main	Kit.	Serv.
Orientation			N	S	W		W	W	W
volume	ft3	681	275	367	1790	238	1239	468	156
MASS	Lb	70175	28368	37824	184392	20267	127656	48226	16075
Sum ext.walls	lb	70175		250584		20267	191957		
Total Int.walls+ceiling+floor	lb		154743						
Total ceiling+floor, ext.& int.walls+courtyard(except main court)	lb		597284						
		Bulk int. mass density (weighted to mass) =				58	Density=		103

	Internal walls	exterior walls	ceiling	Floor	courtyard walls	First floor
Totals	822801	1072915	183929	0	857873	2937518

Second floor

SE wing: Grand summer hall upper void

		int.walls	xternal walls				ceiling
Orientation			S	E	N	W	
volume	ft3	595	1050	2315	217	1583	1520
MASS	lb	61319	108126	238455	22367	2E+05	1E+05
Sum ext.walls	lb	61319		531974			1E+05
Total Int.walls+ceiling+floor	lb			190492			
Total ext.& int. walls + ceiling	lb			722466			

NE wing: Maids quarter - Master bedroom

		int.walls	External walls				ceiling
Orientation			N	W	S	E	
volume	ft3	3484	596.74	548	595	212	747
MASS	lb	358820	61464	56409	61319	19279	63486
Sum ext.walls	lb	358820		198471			63486
Total Int.walls+ceiling+floor	lb			422305			
Total ext.& int. walls + ceiling	lb			620776			

	Internal walls	exterior walls	ceiling	Floor	courtyard walls	Second floor
Totals	420138	730445	192659	0	0	1343242

VITA

Amr Bagneid holds a Bachelor of Architectural Engineering from Cairo University (1979) with a distinction grade for his graduation design project, and a Master of Environmental Planning (Solar Architecture and Energy Technology) from Arizona State University (1987). An early report from his master's research (Courtyard Bioclimates: comparative experiments), written while experiments were still unfinished, was the only selection that addressed climate-control science among 87 participants from over 30 countries for King Fahd Awards, Istanbul, Turkey (1986). The jury reported: "Your entry was very evocative and potentially the first step towards a valuable contribution to this field."

Mr. Bagneid received his Ph.D. in architecture from Texas A&M University in the summer of 2006. His Ph.D. research contributed to the current generation of building simulation software by introducing what is considered to be the first calibrated computer simulation program for predicting courtyard microclimates. This research was supported and acknowledged by four nationally competitive grants: an American Society of Heating, Refrigerating, and Air-conditioning Engineers (ASHRAE) Graduate Grant-In-Aid, in addition to three consecutive American Institute of Architects and American Architectural Foundation (AIA/AAF) Fellowships for Advanced Research. An additional interest of Amr's research is focused upon view aspects in window design.

Mr. Bagneid taught at Arizona State University, King Saud University and Texas A&M University. His teaching expertise includes: Visual Communication, Design Graphics, Scale Models, Basic Design [2-D&3-D], introductory architectural design (Design Foundations and Architectural Design I); Architectural Design Studios including Sustainable Design Studio with emphasis on Climate Responsive Architectural Design; and Environmental Control Systems. Mr. Bagneid may be reached by mail at 15c Ibn Radwan Altabib St., 8th floor, Giza, Egypt. His email address is <amr_bagneid@yahoo.com>